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Prepared For:
U.S. Department of Energy
Assistant Secretary for Conservation
and Renewable Energy
Biomass Energy Technology Division and
Technology Development and Analysis Division
Under Contract No. W-7405-ENG-92

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SYSTEMS STUDY OF ANIMAL FATS AND VEGETABLE OILS FOR USE AS SUBSTITUTE AND EMERGENCY DIESEL FUELS

by

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INTRODUCTION

Diesel fuels are playing an increasingly important role in energy applications in the United States. In addition to a strong position in over-the-road transportation for movement of goods by truck and rail, United States agriculture is largely operated with diesel machinery. Agriculture uses approximately 3 to 5 percent of United States energy for production purposes. Implementation of an agricultural diesel fuel program that provides a comparable quantity of diesel fuel could offset this petroleum consumption, according to a concept advanced by Dr. Charles Peterson of the University of Idaho. Gasoline usage is likely to decline because of rising fuel efficiency in the automotive fleet. However, no such decline is envisioned for diesel fuel, which is likely to increasingly be consumed in existing applications and to increase its share of personal transportation fuel usage. Therefore, diesel fuel is likely to play a greater role in the future and is likely to be a critical element in any future fuel shortages.

Because middle distillate fuel consumption exceeds 45 billion gallons per year, of which 23 billion gallons is diesel fuel, DOE is seeking substitutes for petroleum-derived diesel fuel. The Biomass Energy Technology Division of the U.S. Department of Energy has a mandate to develop new fuels from agricultural, silvicultural, and aquatic biomass resources, and the Office of Vehicle and Engine R&D has a mandate to investigate the suitability of alternative fuels derived from domestic resources including coal, oil shale, and biomass. Replacement of some of this critical petroleum fuel supply by use of renewable resources is a highly appropriate goal. DOE's Transportation Systems Division is charged with the evaluation of alternative fuels. Therefore, these two DOE divisions jointly sponsored this Battelle-Columbus program.

Vegetable oils and animal fats have physical and chemical properties that correspond rather closely to those of middle distillate fuels. That is, the heat of combustion and combustion characteristics of triglycerides are similar to petroleum-derived middle distillate fuels. The United States has productive capacity of more than 2 billion gallons per year of fats and oils. Substantial inventories of fats and oils are geographically dispersed throughout the United States, a factor that could be very beneficial in a sudden fuel emergency situation. Many farmers know how to grow oilseed crops and could produce a portion of their diesel fuel.

Battelle Columbus Laboratories conducted this program for the Department of Energy to provide information that DOE could use for planning a multiyear research and development program on these alternative fuels.

Project Objectives

The primary objective of the research program was to provide DOE with information for multiyear research and development of fats and oils as emergency fuels. To achieve this primary objective, the following subobjectives were undertaken.

- Botanical description of candidate crops
- Discussion of the status of U.S. production of fats and oils and the crops that yield fats and oils
- Information pertaining to the present and future possible costs of oilseed crops, oils, and fats
- Utilization patterns for fats and oils
- State of the art in oilseed processing
- Initial evaluation of energy balance in production of fats and oils
- Suggestion of viable candidates and the impacts of commercialization of these candidates
- Suggestions for research and development pertaining to outstanding candidates.

The program has been designed to be a springboard for major new initiatives and programs by DOE.

Scope of the Program

The research program has included both vegetable oils and animal fats, but does not include waxes, terpenes, or tannins. The intent is to provide DOE with information pertaining to strategic alternatives.

Systems Overview

The production and use of vegetable oils and animal fats for diesel fuel substitutes would be the result of the functioning of fairly complex systems. As shown in Figure 1, the vegetable oil system is comprised of three major subsystems. The crop production subsystem uses the fundamental factors of production (land, labor, capital, technology, and energy) to provide an oilseed output, along with crop residues. The oilseed output in turn is the raw material for a separation subsystem that yields crude fats and oils, plus a protein-containing meal by-product. The crop residues may either provide energy for the separation process or nutrients for the crop production system.

The crude vegetable oils are refined and/or transformed and formulated into diesel fuel products. Typical purification processes include degumming to remove phosphatides, winterizing to remove high melting components, and alkali refining to remove free fatty acids.

The protein-containing by-products are sold to animal feed/food markets. The final vegetable oil products might also be sold to food markets or to industrial markets.

The animal fat system differs significantly from the vegetable oil system in that animal fats arise as by-products of meat production for food applications. As shown in Figure 2, the factors of production are employed to produce livestock that are slaughtered and trimmed to meet the requirements of food market customers. Fatty wastes arise at numerous points in livestock production and meat processing subsystems, including slaughterhouse wastes, dead animals, and supermarket butchershop trimmings. These rendering raw materials are subjected to a cooking and solvent extraction process that separates crude animal fats from protein-containg products.

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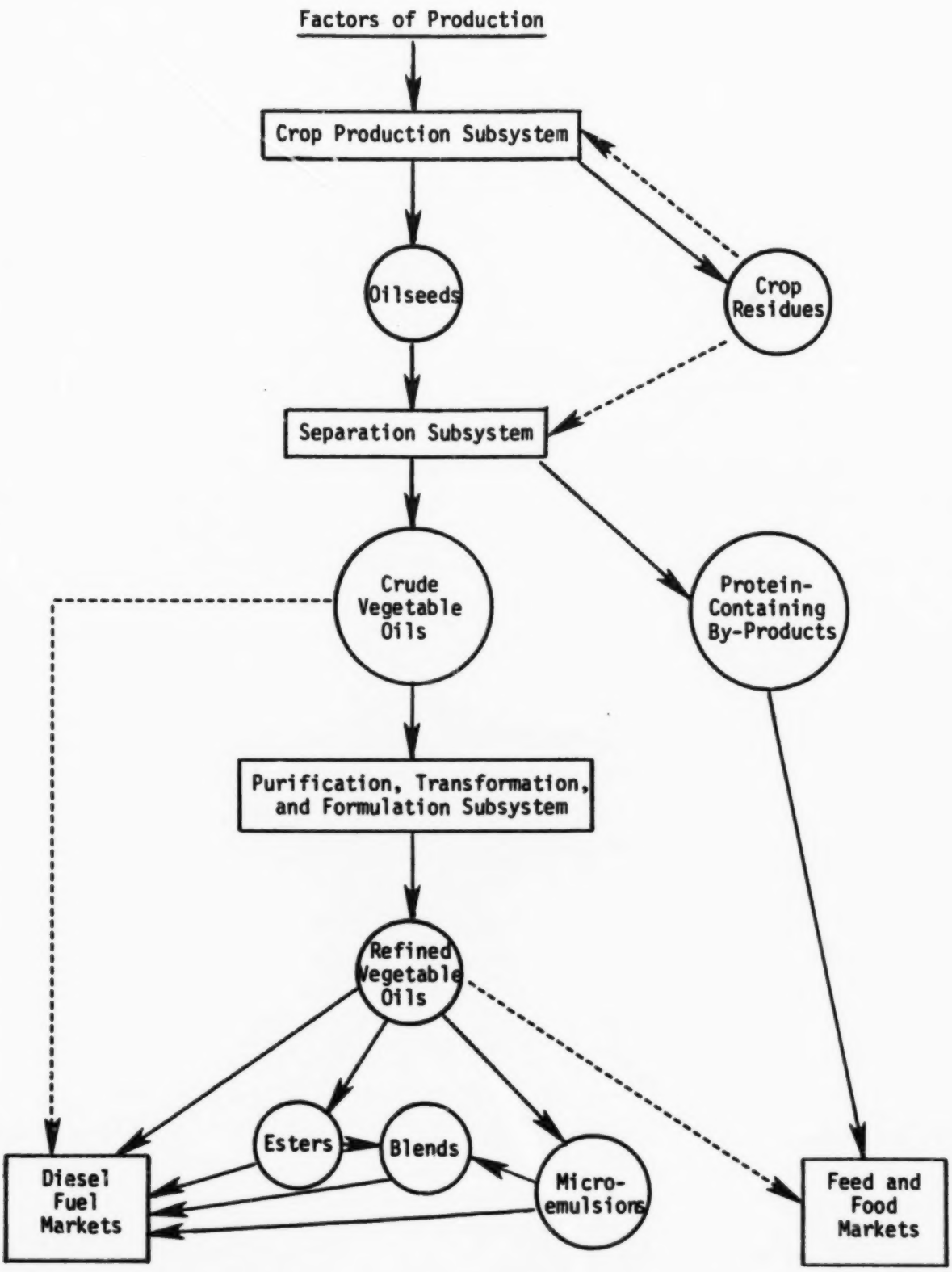

FIGURE 1. OVERVIEW OF VEGETABLE OIL SYSTEMS

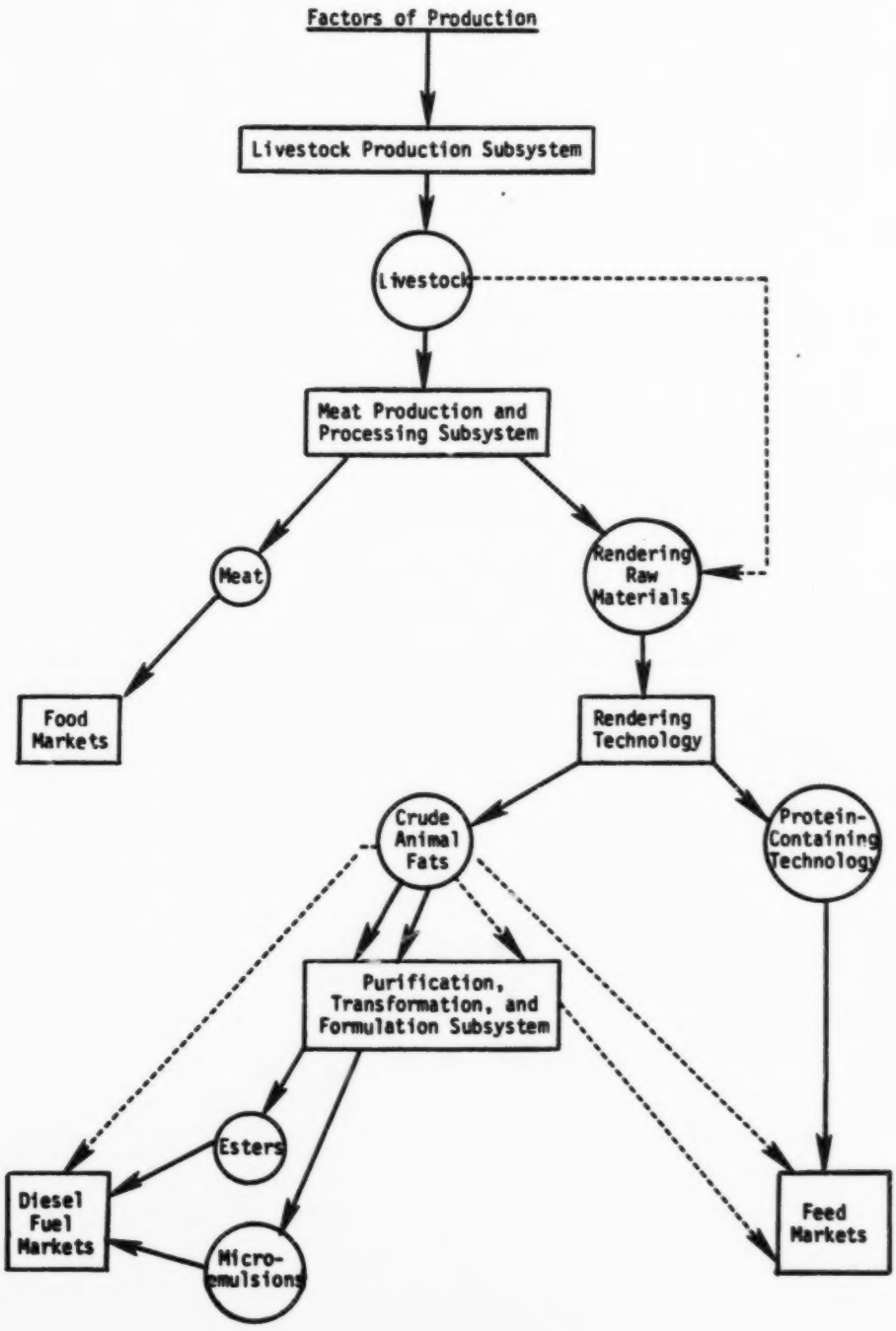

FIGURE 2. OVERVIEW OF ANIMAL FAT SYSTEM

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The inedible tallow and grease fats arise from the parts of the animal that are microbiologically contaminated or otherwise unfit for human consumption. The protein-containing products go to feed markets. The crude animal fats may also go to feed markets or to chemical, soap, and export markets.

Crude animal fats from rendering could be purified and transformed into esters or microemulsions similar to those that could be obtained from vegetable oils. It is unlikely that the high melting crude animal fats could be used directly in diesel fuels, but appropriate blends might be evaluated for use in warm climates.

Organization of This Report

A concise, management-oriented report is provided for use by decision makers. Detailed results are presented in the following Appendices:

Appendix A: Technical Information on Vegetable Oils and Animal Fats – features brief profiles of the botanical, agronomic, and compositional aspects of twelve major resources for production of fats and oils.

Appendix B: Economic Information on Vegetable Oils and Animal Fats – provides data on current production, applications, and economics of the major products that might be used as diesel fuel ingredients.

Appendix C: Production Potential for Oilseed Crops – discusses means to increase oilseed production, based on availability of land of various levels of quality and opportunity for crop improvement.

Appendix D: Economics of Vegetable Oil Recovery – presents data and scenarios for three possible local and regional oilseed processing facilities designed to provide emergency diesel fuel substitutes to agricultural users of diesel fuel.

Appendix E: Diesel Fuel Specifications and Vegetable Oil Properties – compares what diesel engine manufacturers and users expect in terms of physical properties and performance with what is known of the relevant properties of vegetable oils and animal fats.

PRINCIPAL FINDINGS

Evaluation of fats and oils as emergency diesel fuels involves numerous considerations pertaining to agricultural production, processing, engine performance, and the associated environmental impacts, and micro/macro-economics. Details pertaining to this evaluation are presented in the Appendices to this report, as described in the preceding section.

Leading Issues

The United States now uses about 23 billion gallons per year of middle distillate fuels for transportation. Diesel fuel consumption can be expected to rise substantially in the next 20 years as automobiles shift from gasoline to diesel fuel. U.S. agriculture uses about 3 billion gallons of diesel fuel per year. Non-transportation uses are an additional 22 billion gallons per year.

The concept of using diesel fuels derived from vegetable oils or animal fats appears to be technically feasible. However, many technical, economic, and institutional issues are unresolved at this time. Leading issues pertain to:

(1) Impacts of prolonged use of these triglyceride fuels on engine durability and performance
(2) The macro-economic impacts of their use
(3) The micro-economic impacts of using these resources for fuels
(4) The optimum scale of production for vegetable oils and the extent and preferred methods of purification required to achieve a useful fuel at reasonable cost
(5) Optimum blends or chemical derivatives to produce effective but economical fuels

(6) The response time in emergencies

(7) Selection of the most appropriate fats and oils for fuel use, taking into account composition, agricultural income, consumer cost, and foreign exchange considerations.

The Project Team concludes that these issues can be resolved successfully, but they need to be addressed systematically.

Sunflowers and peanuts are attractive oilseed crops for fuel use because of their high oil content (approximately twice that of soybeans or cottonseed), useful protein co-products, and the state of the art of production. Sunflowers and peanuts have relatively loose linkages to animal feed and food markets, compared with soybeans. These loose linkages diminish the negative impacts of using the oil for fuel. Diversion of existing oilseed production or processing capacity for diesel fuel use would be counterproductive because prices of food and industrial products would rise rapidly. The Project Team concludes that increased production is more desirable.

A near-term emergency fuel program probably will include soybean oil, because it is the most available and least expensive vegetable oil. However, it is tightly linked to food, feed, and foreign exchange-generating markets. A separate strategic planning study would be needed to optimize management of this crop for use in extreme emergencies (e.g., OPEC embargo or nuclear crisis).

The fuel market also provides opportunity to reduce agricultural surpluses in vegetable oils, thus improving agricultural revenues and the United States trade balance. For example, soybean oil inventories amount to approximately 250 million gallons in the fall of 1981, thus reducing prices and farm income. Diversion of part of this surplus to diesel fuel use could be beneficial to the United States economy.

Animal fats (inedible tallow and grease) are the least expensive triglyceride resources and could be diverted in part to fuel use immediately. The economic consequences of such a move on the prices of industrial product and on foreign exchange are complex but probably favorable.

Animal fats (inedible tallow and grease) are the least expensive triglyceride resources and could be diverted in part to fuel use immediately. The economic consequences of such a move on the prices of industrial product and on foreign exchange are complex but probably favorable.

Oilseed energy crops that have no existing markets (e.g., the Chinese tallow tree or microalgae) permit minimal disruption of existing markets, but the time to achieve large scale production is extended considerably.

This investigation indicates that opportunities exist to use approximately 20 million to 25 million acres for oilseed production, including sequential (usually double) cropping to provide one billion gallons of diesel fuel per year. An intensive agricultural development program might achieve a goal of enough oilseeds to make possible the production of 5 billion gallons of diesel fuel per year, exceeding the expected agricultural demand for this class of fuels in 1996. However, it is unlikely that fats and oils can replace much more than about 10 percent of the total middle distillate demand of 40 billion to 50 billion gallons per year.

Economic Considerations

The United States produces about 2 billion gallons of vegetable oils and animal fats per year. Average inventories amount to approximately 250 million gallons. Soybean oil represents about 57 percent of U.S. production and animal fats account for about 29 percent. For oilseeds to make a major impact, it is not useful to divert existing production that would make a relatively small contribution to total diesel fuel needs. Additional oilseed crops need to be produced, either by adding crop land or practicing sequential crop production as discussed below. Oilseed production costs are estimated on a per-acre basis, with yields subject to the impacts of weather and pests. Conventional crop production methods yield costs that are high compared with existing diesel fuel prices. Yields decline as more marginal acreage is brought into production or when second crops are planted and harvested. Emergency prices for diesel fuels of $2.00 or more per gallon can be expected.

The gap between the selling price of diesel fuel and fats and oils is closing rapidly. For example, soybean oil was 4.5 times the selling price of diesel fuel 5 years ago and now is approximately 1.7 times as much. Lower grades of animal fats are now available for approximately the same price as diesel fuel.

Commercial oil facilities tend to be quite large by agricultural and chemical industry standards but small by petroleum and coal production standards. A leading issue is whether huge facilities in the 2000-ton-per-day class should be built or whether small backyard plants rated at less than 1 ton per day should be built.

The 600 million gallons per year of inedible tallow and grease that arise from processing livestock are the lowest price triglyceride products (usually 20 percent less than soybean oil). The high melting point of animal fats would cause fuel line clogging, necessitating conversion to less viscous products. The by-product status of fats is a drawback for large volume diesel fuel use because supply cannot be increased in response to increased demand.

Production Potential for Oilseed Crops

The production potential for oilseed crops depends on various means to increase the quantity of land devoted to oilseed crop production and the use of various crop improvement strategies and agronomic practices to improve yields. The land resource can be increased by sequential cropping or crop rotation on relatively high quantity land or by use of land that is considered marginal for crop production now (e.g., pasture, range, or forest lands).

Sequential cropping involves growing more than one crop per year on a plot of land. Sequential cropping opportunities are regional in geographical scope and can constitute environmental hazards in some areas. The focus would be on short maturity oilseed crops (e.g., sunflower which can mature in 95 days). An example would be Ohio winter wheat, followed by sunflower.

Changes in crop rotation in which (for example) sunflower (instead of soybeans) is rotated with corn might be a means to increase vegetable oil production at the expense of protein production.

A diesel fuel substitute potential of 5 billion gallons per year arises from crops grown on new lands, sequential cropping, changes in crop rotation patterns, new oilseed crops, and some diversion of animal fats from export markets (Table 1). Although there are sufficient agricultural resources in the United States to permit production of approximately 5 billion gallons per year of triglyceride fuels derived from vegetable oils and animal fats (Table 1), there is considerable doubt concerning the existence of entrepreneurial incentives, national determination, capital, or infrastructure required for such a huge undertaking in the United States at this time.

The food-versus-fuel controversy arises whenever cereal or oilseed crops are considered for fuel production. One way to view the food-versus-fuel problem is that agricultural production to obtain the maximum quantity of oilseed should be encouraged. Depending on the selling price and availability of petroleum and food/feed vegetable oil products around the world, the vegetable oil should be shunted into the appropriate end uses. This full agricultural production concept is to be contrasted with limitations of acreage and other measures designed to obtain high agricultural revenues for the United States by restricting output. When output is restricted, the United States is prepared neither for an OPEC embargo-type emergency nor for crop failure-type emergencies in countries that are less well endowed with land and good weather. In this view, there is not a conflict between food and fuel, but a conflict between full production and artificial limitations on production.

The development of new technology to render woody biomass about as digestible as hay may liberate significant U.S. pasture and range land for oilseed crop production without placing undue pressure on red meat production and pricing. The oil in the oilseed crops can be used as fuel and the protein (plus the synthetic hay) can be fed to cattle to provide sufficient red meat production. This approach would necessitate a major change in cattle feeding practices that would involve considerable nutritional and economic research to verify or disprove its feasibility.

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TABLE 1. U.S. AGRICULTURAL POTENTIAL FOR ADDITIONAL FATS AND OILS PRODUCTION FOR DIESEL FUEL USE

Source	Basis for Estimate	Estimate, [Billion Gallons Per Year][a] Near Term[b]	Long Term[c]
Animal fats	20 percent of 1980 exports	0.1	0.2
Crop rotation	20 million acres at 60 gallons per acre, with 1/3 available the first year that sufficient processing equipment is available	0.4	1.2
Sequential cropping	25 million acres at 40 gallons per acre[d] with 20% available the second year that sufficient processing equipment is available	0.2	1.0
New cropland from pasture, range, and forest	20 million acres at 40 gallons per acre[e]	0.2	0.8
New oilseed crops (e.g., Chinese Tallow tree)	10 million acres at 170 gallons per acre		1.7
Total		0.9	4.9

(a) Agricultural potential for raw materials containing indicated amounts of fats and oils suitable for diesel fuel use. Time frame for construction of facilities to extract this much oil must be estimated separately.

(b) Near term is within one or two years of the onset of an emergency of sufficient magnitude to stimulate intensive implementation.

(c) Long term is 15 years after onset of an emergency of sufficient magnitude to stimulate intensive implementation.

(d) Yields 25 percent less than the U.S. average for the crop are assumed because the timing of planting and/or harvest usually will be suboptional.

(e) Yields 25 percent less than the U.S. average for the crop are assumed because less fertile land is used.

Source: Battelle-Columbus estimates, based on information in Appendix C of this report.

Oilseed Processing

Concepts for local production of vegetable oil in on-farm units producing about 7000 gallons per year or in cooperative units producing about 160,000 gallons per year were studied in this program. The former requires about 130 acres and the latter about 2500 acres, if sunflower is the typical crop. Correspondingly, more or less acreage would be required for other crops. U.S. diesel fuel usage on farms is approximately 6 gallons per acre; therefore, each acre devoted to oilseed production provides about enough diesel fuel to farm approximately 8 to 10 acres. This estimate assumes that neat vegetable oil could be used. The present state of the art requires blending of the oil with sufficient conventional diesel fuel to attain operable fuel viscosity.

A commercial unit processing 200 tons per day of sunflower might be used to supply the agricultural diesel fuel needs of about one million acres of typical farmland. The output of about 100,000 acres would be needed. Peanuts might be almost twice as effective, due to higher yields but unit costs may not be better.

Research at the North Dakota State University and the University of Idaho indicate that mechanically adept farmers may be able to assemble and operate on-farm or cooperative oilseed processing systems. The problems of the on-farm processor are a small fraction of those encountered in production of on-farm ethanol. A major challenge will be the achievement of adequate vegetable oil purity to protect the diesel engines from harm.

Minimum processing costs should be achieved in large-scale facilities in the range of 1000 to 3000 tons per day. However, such facilities serve national and international food and industrial-product markets and draw on the production of hundreds of thousands of acres of farm land. The raw materials are brought in from great distances. Although processing costs are thus minimized, raw material costs and transportation costs are increased. Large scale oilseed processing ventures originally designed for fuel production may sell to food markets because they would find it profitable to meet fuel oil specifications. Small, local facilities in rural areas are more likely to produce fuel-grade vegetable oil without disruption of food markets.

A preliminary, order-of-magnitude economic analysis was conducted to compare the cost of vegetable oil-derived diesel fuel at three scales of operation

(1) On-farm (87 tons per year)

(2) Cooperative (1600 tons per year)

(3) Commercial (63,000 tons per year).

The assumption for oilseed cost and by-product credit reflected the scale of the facility. The on-farm unit was assumed to have sunflowers available for $130 per ton which does not recover full oilseed production costs. The commercial facilities would pay the full costs, profit, and transportation to the facility. The local cooperative was assumed to be between these extremes. The by-product credits reflect the ability to achieve a higher quality product with a larger scale facility. Costs and credits for the peanut case were developed similarly.

An intentionally irregular accounting system was used by the Project Team to reflect the fact that a farm is not a miniature factory. The capital investment for an on-farm unit that produces about 7000 gallons per year is estimated to be about $25,000. A capital charge of $4,500 per year is assumed. The capital cost of the installed plant is held down by the use of the farm unit's labor to do some of the plant erection and by use of existing farm buildings and some second-hand agricultural equipment. The operating costs for the on-farm unit total $8,500 per year (about $1.20 per gallon). The farm labor wage rate is assumed to be $6 per hour. The costs of oilseed, profit, supervision, and overhead charges are not included. Although some farmers may be capable of maintaining the expeller and other equipment, the cost of equipment overhaul may be high in the general case.

The capital cost of a cooperative unit might be approximately $260,000 for a facility to process about 1600 tons per year of sunflowers into about 150,000 gallons of sunflower seed oil. A cooperative peanut processing facility would be quite similar in capacity and cost. The operating cost of the cooperative system would total approximately $200,000 (about $1.33 per gallon of diesel fuel product), provided that the cooperative accepted a minimal overhead and no profit was included. Provisions were made for the costs of direct labor and supervision. Nevertheless, the economics

of the cooperative unit can be considered irregular and optimistic in that they are aimed at local self-sufficiency and zero profit during times of discontinous availability of diesel fuel.

A 200-ton-per-day commercial unit to process 63,000 tons per year of sunflower seeds into 6 million gallons per year of fuel grade sunflower seed oil might cost about $2.8 million. Its operating cost would total about $2.5 million per year (about $0.42 per gallon). The commercial-scale facility no longer uses irregular economics but has provision for overhead and profit.

Using these assumptions, on-farm sunflower seed oil would cost $1.85 per gallon of diesel fuel equivalent, cooperative-scale sunflower seed oil would cost $2.20, and the commercial-scale unit would sell its product for $1.76 per gallon, including allowance for a profit. The corresponding costs for the peanut case are: on-farm, $1.81 per gallon; cooperative, $2.08 per gallon; and commercial, $1.77 per gallon. The on-farm and commercial costs are equivalent in this type of order-of-magnitude estimation. However, it is likely that the cooperative scale does have a higher cost. The Project Team chose a peanut that cost 20 percent higher than sunflowers. The detailed calculations are presented in Table D-8 of Appendix D so that the reader can substitute other assumptions.

When by-product credits for protein meal are taken into account, the 200-ton-per-day facility yields minimal cost, the on-farm unit is second, and the cooperative appears much less attractive.

Larger solvent-extraction facilities are expected to yield less expensive oil and be capable of delivering a more reliable product. However, facilities in the 1000 — 3000-ton-per-day range could have much more adverse impact on the conventional fats and oils economy.

In a large, efficient facility, approximately $0.38 per gallon of oil should cover the cost of assembly, storage, and crushing operations. This estimate assumes an existing plant built when interest rates were low but before special credits were available. It also assumes a status-quo protein market to absorb part of the processing costs.

Initial intuition favors the cooperative-sized facility but the need to employ and pay labor and supervisors and to meet the numerous requirements of a business impairs its viability. Smaller cooperatives in

which two or three individuals share the capital cost and labor requirements for a small unit could be quite viable.

Small-scale vegetable oil production entails several potential problems not encountered in the existing large-scale oil extraction industry:

(1) The protein meal will contain more than 10 percent oil (around 14 percent) which renders the product unstable and even spontaneously combustible in some circumstances.

(2) The meal must be mixed with low fat rations to perform well in feeds

(3) The oil may contain many constituents that are injurious to diesel engines that are not found in conventional commercial oils

(4) Quality control will be difficult to conduct in an informal agricultural setting.

These problems are not insuperable. For example, it appears that the problem of fines in the crude vegetable oil has been solved at North Dakota and Idaho by use of cartridge filters (similar to automobile oil filters) which remove this otherwise injurious constituent of crude vegetable oil mixtures.

The suitability of oilseed processing units for acute emergency use remains open to question. Processing units probably would not be bought for use only in emergencies because their cost cannot be justified. If bought, they will be used whether an acute emergency exists or not. The percentage utilization might be increased during crises.

Energy Balance

The total processing energy requirements are approximately 15,000 to 20,000 Btu's per gallon of vegetable oil. Because vegetable oil contains about 130,000 Btu's per gallon, the energy required to conduct this processing is a relatively small percentage of the total. The energy required to grow oilseed crops varies widely, depending on the species selected.

For example, soybeans require virtually no nitrogen fertilizer but sunflower production requires substantial quantities of this energy-intensive nutrient. The energy requirement is thereby doubled. The energy required to grow enough sunflowers to produce one gallon of oil is approximately 32,000 Btu's, after taking minimal credit for the energy contained in the protein co-product. Thus, the energy gained in using vegetable oils for fuel appears to be approximately 80,000 Btu/gallon. Thus, the energy output-to-input ratio exceeds 2.5 for sunflowers and is still more favorable for legumes requiring little nitrogen fertilizer. When sunflower seed or peanut hulls are used for fuel in the process, the results are improved by about 6000 Btu's per gallon.

Diesel Fuel and Engine Considerations

Vegetable oils have heats of combustion that are within about 5 to 10 percent of that of standard diesel fuel derived from petroleum. Although the measured cetane numbers of vegetable oils are less than diesel fuel, the knocking qualities seem to be adequate in preliminary tests. The ash and sulfur contents of vegetable oils are excellent.

The major potential drawbacks to use of vegetable oils as diesel fuel include:

(1) Fuel line and filter clogging due to fines, phosphatide gums, waxes, or high melting saturated fats

(2) Polymerization or partial oxidation during storage which raises viscosity above published values

(3) Polymerization in the combustion chamber due to heat or free radicals which lead to deposits

(4) Poor ignition and combustion characteristics (e.g., fuel consumption) resulting from improper atomization due to high viscosity

(5) Coking

(6) Fouling or polymerization in the lube oil due to blowby of unsaturated fuel capable of autoxidation.

Many diesel fuel - vegetable oil combinations may be acceptable for short-term emergencies involving hours or a few days. Acceptability of vegetable oils for long-term usage requires that these potential drawbacks be more thoroughly defined and, if serious, reduced or eliminated.

Methyl esters with low viscosities approaching that of diesel fuel can be made from vegetable oils by treatment with methanol. The glycerin by-product is valuable for chemical uses. Removal of this possible acrolein precursor is environmentally desirable as well. However, the methyl esters of saturated fatty acids still tend to solidify in cool weather conditions and methyl ester products are still subject to the free radical polymerization problems associated with build-up in crankcase viscosity and coking.

Microemulsions of vegetable oil products with alcohols and water in diesel fuel are under development by several organizations. Experimental emulsions have been prepared that are low in viscosity, stable in storage and have apparently favorable performance characteristics. More data are needed regarding the long-term performance of these products.

Vegetable Oil Emissions

There are no existing regulations for diesel emissions when the fuels are used on farms or in other off-the-road applications. Particulate and gaseous emissions standards have been established for mobile applications of diesel engines (trucks, busses and passenger cars), and close attention has been given to certain non-regulated emissions because of potential health hazards. Enough data to assure the public that health and safety will not be threatened by the use of fats and oils in diesel engines need to be accumulated.

Research and Development Needs

A concerted research and development program will be needed to make possible the substantial use of vegetable oils as diesel fuels. The overall program is depicted in Figure 3. The program's most critical element is further determination and comparison of studies on the effects of various fats and oils on the durability and performance of diesel

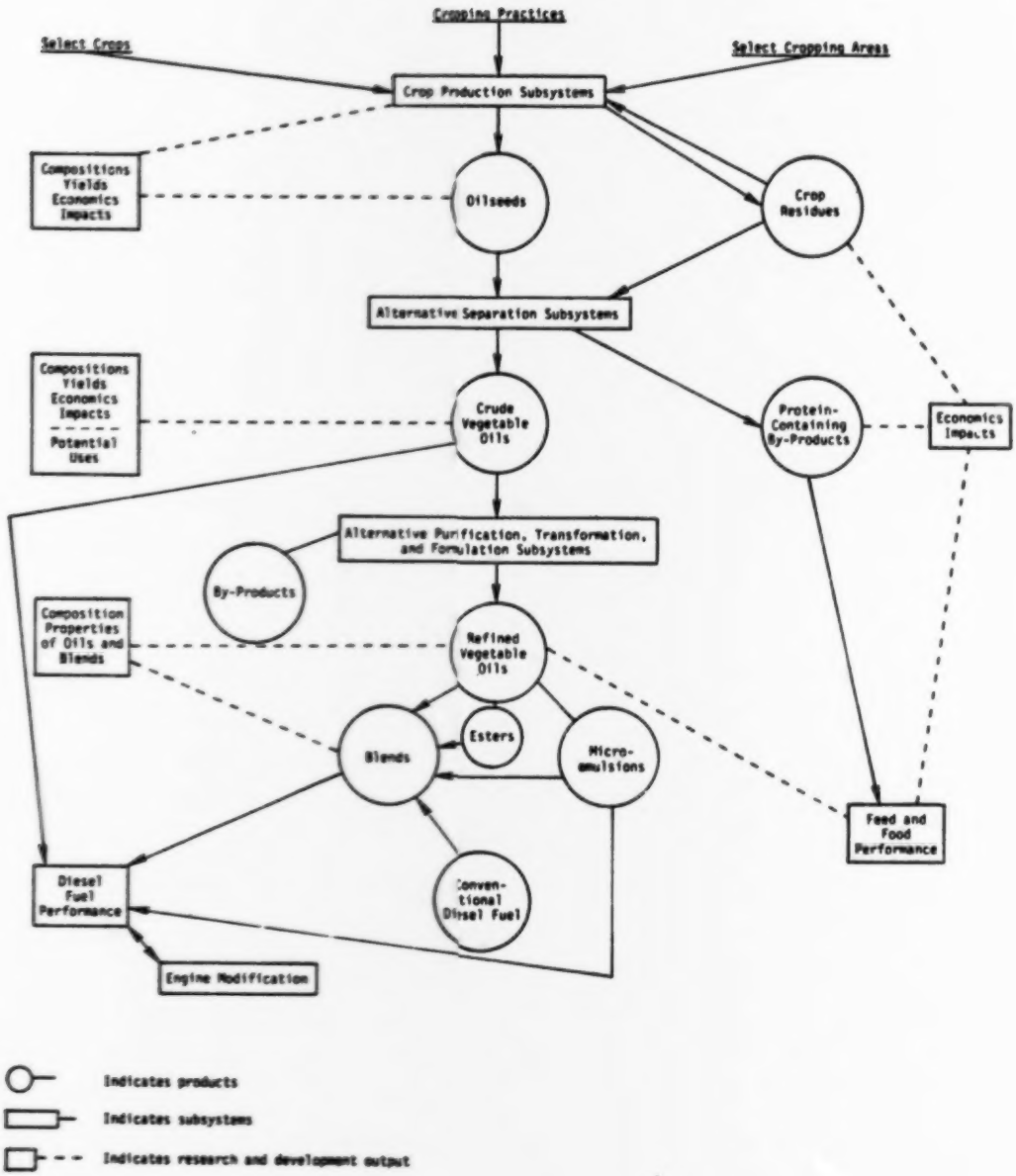

FIGURE 1. OVERALL PROGRAM

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engines. For each oil, it will be necessary to evaluate various purity levels that are associated with more or less processing. This will establish which oils are acceptable at which level of purity. The oils that fail may be modified to achieve acceptance through separate programs. The processing systems need to be developed to achieve the desired levels of purity at reasonable costs. Crop production needs to be enhanced by selection, breeding, and improved agronomic practices for those crops that appear to be attractive on both technical and economic grounds.

Research and development on conversion of fats and oils into diesel fuel products through interestification, microemulsification, etc. involves process investigations, performance trials, and research to determine capital and operating costs. Such studies should be geared to overcoming serious technical and/or economic drawbacks of the fats and oils from which the derivatives are made.

Fuel performance evaluations should be phased so that in-depth evaluations are conducted only on fuels that pass screening criteria regarding physical properties and economic attractiveness. In the in-depth studies which should begin from a position in which the vegetable oils have been completely characterized:

- The types of engine should be those that are (or will be) used by the customers
- Durability tests should represent long runs using test cycles approved by the Engine Manufacturers Association
- Adequate testing should take place with vehicles or engines under adverse weather conditions
- Failure evaluations involving fuels that have become contaminated with fines or high viscosity ingredients should be conducted so that the sensitivity of engine durability and performance to fuel composition and purity can be assessed
- Adequate experimental design with respect to replication and statistical rigor should be employed by the investigators.
- Complete vegetable oil characterization.

Information pertaining to crop production practices and production budgets for fuel-grade peanuts, rape, and Chinese tallow tree needs to be developed and evaluated for various cultivars in various

geographical areas. Even soybeans and sunflowers, for which more information is available, have serious uncertainties when they are to be used in sequential cropping systems.

The in-depth research and development on crop production should involve only those crops that pass both agronomic and economic screening criteria. Programs should use well-replicated experimental designs with field plots of adequate size. The emphasis should be on regional studies that are meaningful in geographical scope.

Although impact of using fats and oils on the durability of diesel engines is the most urgent problem requiring research attention, an economic problem may outrank durability in importance. Price elasticity theory would predict that either diversion of fats and oils or production of additional fats and oils could cause large price changes in these commodities. The state-of-the-art in price elasticity theory is not well advanced, especially for long-term situations in which there are opportunities for changes in the acreage planted and/or changes in inventories. The project team urges that priority be given to achieving increased understanding of price elasticity phenomena through dynamic simulation studies. Crop production studies and engine tests provide tangible results. However, they could be counterproductive if the effect of the development is to cause vegetable oil prices to soar through diversion to fuel use or protein prices to plummet as supplies of this by-product derived from oilseeds exceed demand.

For Further Information

The literature concerning fats and oils/diesel fuel systems is proliferating rapidly. For readers seeking information, the noise level is rather high. Therefore, a brief bibliography of selected sources is presented here. Once these items have been assimilated, the voluminous literature can be approached more efficiently.

For those concerned with crop production, Martin, et. al. (1976)*[1], "Principles of Field Crop Production", provides an excellent

* The list of References begins on page 23.

overview. Many state universities have established oilseed production programs that provide insight into agronomic and economic problems of these crops [Auld, et. al., 1980[2] and Hofman, 1980[3]].

A broad overview of the composition, properties, and reactions of fats and oils is provided in the Fourth Edition of Bailey's Industrial Oil and Fat Products", edited by Swern (1979)[4]. The monograph on "Fatty Acids", edited by Pryde (1979)[5], provides comparable information on fatty acids and their derivatives. Applewhite's (1980)[6] concise, 30-page summary of the properties of fats and oils is provided in the Third Edition of the Encyclopedia of Chemical Technology. Oilseed and vegetable oil processing technology was the subject of an international conference in 1976. The proceedings of this conference which have been published by the American Oil Chemists Society[7] provides the most concise and authoritative information in this area.

The agronomic, chemical, and chemical engineering information provided in the monographs cited above take virtually no notice of the possible use of fats and oils in diesel fuel systems. Information on this aspect can be obtained from some major publication authored primarily by agricultural engineers. The North Dakota State University group has published two key articles on the performance of diesel fuel/sunflower oil mixtures [Kaufman, et. al., 1981[8]]. The University of Idaho is also active in engine performance tests on vegetable oils derived from crops growing in that region of the United States [Peterson, 1981[9]]. The use of sunflower oil has been explored also in pioneering work in South Africa [Bruwer, et. al., 1981[10]]. Australian research [Stewart, et. al., 1981[11]] on a wide variety of oilseeds is being actively pursued. Opportunities for fuels and chemicals from novel oilseeds, including Chinese Tallow, have been reviewed recently in Chemical and Engineering News [Morgan and Schultz, 1981[12]].

The United States Department of Agriculture's Northern Energy Center is sponsoring a series of conferences pertaining to the use of vegetable oils as diesel fuels, especially for agricultural uses[12]. Proceedings of some of these conferences are becoming available and may be obtained from the Publications Department of the USDA Extension Service in Washington, D.C.

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(6) Applewhite, T. H., "Fats and Fatty Oils" in Kirk-Othmer's Encyclopedia of Chemical Technology, Third Edition, No. 9, Wiley, New York, 1980, p 795.

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(11) Stewart, G. A., et. al., "Oil Seeds as a Renewable Source of Diesel Fuel", Search, 12 (5), May, 1981, pp 107-115.

(12) Morgan, R. P. and Schultz, E. B., Jr., "Fuels and Chemicals from Novel Seed Oils", Chemical and Engineering News, 59, September 7, 1981, pp 69-77.

(13) Anon., "Alcohol and Vegetable Oil as Alternative Fuels", Proceedings of seminar sponsored by U.S. Department of Agriculture's Northern Energy Center, Peoria, Illinois, April 28-30, 1981.

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APPENDIX A

PROFILES OF SELECTED VEGETABLE OILS AND ANIMAL FATS

APPENDIX A

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APPENDIX A

PROFILES OF SELECTED VEGETABLE OILS AND ANIMAL FATS

The descriptive information provided in the profiles (beginning on page A-6), though not exhaustive, is meant to encourage general familiarity with each of the potential feedstocks for diesel fuel supplementation, and to supply specific details useful for making contrasts and comparisons among these feedstocks. The following discussion briefly highlights several important concepts within the profiles.

Oilseeds

Botanical Description

The taxonomic family of each of the oilseed crops is provided in order to establish general relationships among the selected species. For example, Chinese tallow tree and castorbean are both members of the Euphorbiaceae, or spurge family. Hevea brasiliensis, the source of natural rubber, also belongs to this family. Peanut and soybean belong to the Leguminosae, or pea family, which also includes alfalfa, clover and other agricultural crops, many of which capture and reduce atmospheric nitrogen through symbiotic association with soil bacteria. The process of "fixing" atmospheric nitrogen reduces a plant's needs for nitrogen fertilizer.

Examining the center of origin of the selected oilseed species, indicates that most are plant introductions, i.e., they are not native to the U.S.; for instance, soybeans were introduced from the Orient, and corn from Mexico or Central America. Sunflower, indigenous to North America, is the exception.

The photosynthetic pathway exhibited by the species provides an index of potential photosynthetic efficiency, although it should be noted that actual productivity is dependent on numerous environmental, agronomic, and economic factors. Of the selected species, only corn exhibits the more advanced C_4 photosynthetic pathway.

The growth habit, i.e., whether the plant is annual or perennial, herbaceous, or deciduous, has important agronomic implications. An annual requires yearly planting, whereas a perennial does not. The only true

perennial among the selected oilseed crops is the Chinese tallow tree. Furthermore, the Chinese Tallow tree, which is deciduous, does not produce a harvestable crop until it is three to five years old. The other oilseed crops produce a crop within at least a year.

Morphological characteristics of the individual oilseed crops are provided for general recognition purposes, and because the structure of the underdeveloped species in particular impinges upon the development of a suitable agronomic system. As examples, crambe and winter rape are similar to small grains, e.g., wheat, oats, and may be managed in an analogous manner. Chinese tallow tree, on the other hand, will require very different agronomic techniques.

Chemical Composition

The seed oil content, on a percent dry weight basis, varies greatly among the species. Soybeans, for example, contain approximately 18 percent oil. In contrast, winter rape seeds contain up to 45 percent oil, and sunflower seeds have reached 61 percent oil under experimental conditions. Of course, data for the percent oil content of the seeds should be augmented with seed yields of the various crops in order to provide meaningful comparisons among the selected crops (see yield data, page C-3).

The relative amounts of saturated versus unsaturated fatty acids in the vegetable oils influence certain fuel characteristics, and also non-fuel uses (industrial and food) which compete for the oils. For instance, linolenic acid, a highly unsaturated fatty acid, predominates in flaxseed oil. The chemical reactivity associated with high unsaturation makes flaxseed oil useful as a drying oil (paints, varnishes), but unsuitable as a cooking oil. Sunflower and soybean oil, on the other hand, contain large percentages of oleic and linoleic acid which are more saturated than linolenic, and can be used in cooking. It should be noted that breeding efforts, such as those which have substantially decreased the amount of erucic acid in rapeseed oil, can greatly influence oil composition. Fatty acid distribution is also affected by environmental conditions such as temperature.

Non-oil seed components also vary widely among the oilseed species. Protein, which potentially could contribute to various livestock and poultry rations, ranges from approximately 18 percent (by dry weight) in sunflowers, and up to 40 percent in soybeans. The quality of the protein-rich meal remaining after the oil fraction is extracted from the seed also influences its use as a protein supplement. Castorbean meal, for instance, contains toxins which, if not removed, render it unsuitable for feeding purposes. As another example, flaxseed meal is deficient in two amino acids, lysine and methionine, important to livestock nutrition.

Agronomy

The agronomic descriptions provided in the profiles are not intended to apply to the management of oilseed crops under all conditions. The information is very generalized, and is based predominantly on prevailing agronomic practices and the current development level of the various crops. Obvious qualifications must be made. For instance, management of a crop not only varies under different growing conditions such as soil type, topography, precipitation, etc., but in addition, agronomic practices may vary due to regional traditions or preferences.

Economic factors also influence agronomic practices. Crops which are grown on a wide scale generally are not managed such that the maximum yields are obtained, but in order to achieve optimum economic yields. As an illustration, under heavily fertilized and irrigated conditions, corn can yield over 300 bushels per acre; however, the economic return per acre generally cannot justify the costly fertilizer and irrigation inputs required to achieve such a yield. Growing crops such as oilseeds for fuel purposes also requires integration of the concept of energy balance into the cropping system. The grower is concerned with maintaining a favorable energy input-to-energy output ratio, while still realizing positive economic returns from the crop.

The development level of a crop greatly affects its agronomic requirements and potential. As an example, some crops, such as flax, are reportedly less responsive to fertilization than others, e.g., corn. However, this response is not necessarily a function of an inherent, immutable

ability of one plant species to utilize plant nutrients more efficiently than another. Corn is a more developed crop than flax; genetic manipulation has resulted in the production of numerous hybrids exhibiting diverse characteristics. Similarily, corn is relatively more developed than flax in terms of the agronomic practices, such as fertilization, routinely associated with its management. As another example, safflower production generally has been restricted to drier regions of the southwest U.S. primarily because of its susceptibility to various diseases when grown in wetter environments. However, it is feasible that safflower might be grown throughout a wider geographic range if it were bred for increased tolerance or resistance to these diseases.

Taking these and analogous factors into consideration encourages an open minded approach to evaluating the options available for growing certain crops in various locations. It is important to recognize, however, that the selected oilseed crops exhibit numerous diverse characteristics which also should be considered when developing potential oilseed cropping systems. In terms of geographical range of growth, requirements such as temperature, precipitation, and season length restrict some crops to certain regions. Peanuts require an average optimum July temperature of 81° to 83°F, moderate moisture conditions, and from 110 to 150 frost-free days for adequate growth. The peanut growing region in the U.S. generally has 200 frost-free days. Optimum peanut production, therefore, is restricted to certain regions of the U.S., predominantly in the Southeast.

Growing season requirements also influence cropping schemes applicable to the various oilseeds. Some sunflower cultivars have a 95-day growing season, which allows them to be double-cropped, if desired.

Animal Fats

Tallow and grease refers to the fat rendered from livestock and poultry by-products and animal wastes salvaged for rendering.

There are numerous different types of inedible animal fats, as indicated in the profile on page A-42. Several animals are sources of inedible fats, including cattle, hogs, and sheep. In addition, the nature of the fat is influenced by its position on the animals (for instance, yellow grease is made from the darker colored portion of animals) and the phase of animal processing in which it is produced, (e.g., brown grease is made from catch basins and floor sweepings).

Unlike most vegetable oils, animal fats are high in saturation. As a result, animal fats generally exhibit higher melting points than non-hydrogenated vegetable oils. Titer (hardness or softness of fat) distinguishes tallow from grease. An animal fat is tallow if its titer is 40°C or higher and grease if its titer is below 40°. Most tallow is rendered from beef fat. Cattle slaughter probably provides over 75 percent of tallow production. Grease, obtained mainly from pork fat, depends largely on hog slaughter. Census Bureau reports on production, consumption, and stocks do not show separate statistics for tallow and grease.

Supplies of the various animal fats are dependent on a number of factors including gross livestock production, livestock production cycles, and slaughter levels. In addition, changes in livestock production practices, such as grain feeding versus grass feeding also impact the production of animal fat. The by-product status of animal fats do not permit an increase in production to satisfy increased demand. Instead, the price rises until marginal users surrender.

PROFILES

Twelve leading sources of fats and oils are described in this section of the report. A profile format has been adopted and the resources are arranged in alphabetical order.

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Castorbean (Ricinus communis L.)

Botanical Description:

- member of Euphorbiaceae family
- exhibits C_3 photosynthetic pathway
- annual in temperate zones; short-lived perennial in tropical and sub-tropical regions
- at maximum height, 3 to 12 ft. tall
- in U.S. seeds generally mottled gray, but range from white to black in color

Chemical Composition:

- bean

Constituent	Weight Percent
moisture	4-8
soluble carbohydrates	5-12
protein	14-21
oil	35-50
fiber	15-18
ash	2-3

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- oil (weight percent)

Fatty Acid	Range
Saturated	
palmitic (hexadecanoic)	0.9-1.2
stearic (octadecanoic)	0.7-1.2
Unsaturated	
oleic (cis-9-octadecenoic)	3.2-3.3
linoleic (cis-9,cis-12-octadecadienoic)	3.4-3.7
linolenic (cis-9,cis-12,cis-15-octadecatrienoic)	0.2
ricinoleic ((+)-12-hydroxy-9-octadecenoic)	89 to 89.4
dihydroxystearic	1.3-1.4

Fatty Acid*	Weight Percent
16:0	0.9-1.6
16:1	0.2
18:0	1.0-1.8
18:1	3.2-5.7
18:2	3.7-6.7
18:3	0.2-0.6
ricinoleic	83.6-89.0
dihydroxystearic	0.4-1.3
20:0	0.2-0.5

- castor oil pomace (meal)

Constituent	Weight Percent
Fat	1.7
Fiber	13.2
Crude protein	33.8

- Comments:

  Toxic compounds present in seed are not extracted with the oil and remain in the meal unless destroyed during processing; principal toxic is ricin, a protein; also contains an allergenic proteose and ricinine, an alkaloid; toxic to humans, livestock, and poultry.

---

*Number on left-hand side of colon refers to length of carbon chain; number on right-hand side refers to number of double bonds.

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Agronomy:

- geographical range--adapted to areas with frost-free period of 160 to 180 days; now grown in central and southern Great Plains, and southwestern states in the U.S.; can survive winters in Florida and parts of Texas and California;
- optimum soils--fertile, sandy or clay loam soil which is well drained
- fertility requirements--is not nitrogen-fixing
- growing season--190 days minimum
- moisture requirement--annual precipitation between 15 and 25 in/year; well adapted to irrigated regions
- temperature--average July temperature greater than 76^{o}F
- some agronomic operations not mechanized

Non-fuel Uses:

- oil--when dehydrated used in paints, varnishes; also used in production of sebacic acid, making it a potential substitute to petrochemically derived nylon polymers
- castor pomace or meal--primary application is in fertilizer, also as industrial protein

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Chinese Tallow Tree [Sapium sebiferum (L.) Roxb.]

Botanical Description:

- semitropical member of Euphorbiaceae family
- native to China; introduced as an ornamental tree in southeastern U.S.
- exhibits C_3 photosynthetic pathway
- short-lived (40 to 50 years) deciduous tree
- at maturity, 30 to 40 ft. tall
- resembles aspen or poplar in overall appearance
- monoecious; flowers borne in erect, terminal spikes
- fruit is a capsule, which splits to expose three tallow-coated seeds

Chemical Composition:

• fruit	(weight percent)
moisture	3.9
tallow	32.4*
seed shell	37.0
kernel	26.7

• kernel**	(weight percent)
oil	18-30

*Recent analyses (Scheld et al, 1980) suggest that tallow content is highly variable, ranging from 15 to 30 percent of total seed weight.

**Tallow removed.

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- tallow (weight percent)

Fatty Acid	Variety U.S.	Variety China
Saturated		
12:0 lauric (dodecanoic)	1.9	2.5
14:0 myristic (tetradecanoic)	3.7	3.6
16:0 palmitic (hexadecanoic)	66.3	57.6
18:0 stearic (octadecanoic)	1.2	1.8
Unsaturated		
18:1 oleic (cis-9-octadecenoic)	26.9	34.5

- seed oil

Fatty Acid	Range Reported
C-16:0 palmitic (hexadecanoic)	4.4 - 6.4%
C-18:0 stearic (octadecanoic)	1.0 - 2.64%
C-18:1 oleic (cis-9-octdecanoic)	7.7 - 11.8%
C-18:2 linoleic (cis-9, cis-12-octadecadienoic)	25.8 - 56.3%
C-18:3 linolenic (cis-6, cis-9, cis-12-octadecatrienoic)	24.6 - 42.3%
Trace Components	0.1 - 10.0%
Estolide-linked Group	8.7%

- comments:

  --although no recent analyses of Chinese tallow meal have been reported, a 1948 study of defatted, dehulled meal indicates that the meal should be adequate for use as a livestock feed supplement, baking flours, etc.

  --the seeds of the Chinese tallow tree contain two unusual short-chain fatty acids joined by an estolide linkage.

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Agronomy:

- geographic range--coastal plain from South Carolina to Florida, inward to Louisiana; also in Texas and California.
- optimum soils--thrives on loamy soils near water; particularly well adapted to poorly drained and saline soils.
- penetrating root system allows growth under drought conditions.
- sexual matruity is achieved in trees 3 to 5 years old.
- flowers form at branch terminals, and fruits (capsules) are borne in small clusters; at maturity, the outer brown husk splits open and exposes 3 oval-shaped seeds; the thick, white mesocarp surrounding the seeds contains the tallow.
- seed clusters are susceptible to removal by hand, or potentially, mechanical means.
- reportedly exhibits rapid growth, and ready coppicing and root sprouting.
- shortly after maturity, fruit mesocarp (tallow) may be destroyed by a fungus, Pullularia.
- is being considered as short-rotation, intensive silviculture lignocellulosic crop.
- optimum spacing, fertilization, mechanical harvesting, and other pertinent agronomic factors are currently under investigation.

Non-Fuel End Products:

- tallow--candles, soaps.

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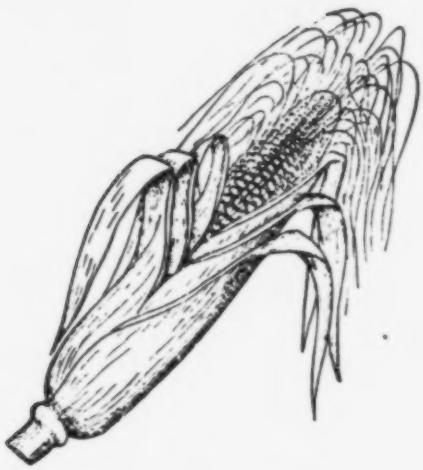
High Oil Corn (Zea mays L.)



Botanical Description:

- member of Poaceae (grass) family
- origin probably in Mexico or Central America, perhaps South America
- exhibits C_4 photosynthetic pathway
- herbaceous summer annual with perennial relatives
- at maturity, ranges from 3 to 12 ft. in height*
- monoecious

Chemical Composition:

- conventional corn kernel

water	13.5
protein	10.0
oil	4.0
starch	61.0
sugar	1.4
pentosans	6.0
crude fiber	2.3
ash	1.4

*Refers to a variety of conventional corn hybrids.

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- the kernels of "high oil" corn hybrids currently available contains 7 percent oil by weight. The genetic lines generally used in breeding high oil corn contain from 15 to 19 percent oil. In order to maintain viability these lines are bred with low oil lines, resulting in the 7 percent level. It is anticipated that a 10 percent level may be achieved with further breeding efforts.

- conventional corn oil (weight percent)*

Saturated

palmitic (hexadecanoic)	7.3
stearic (octadecanoic)	3.3
arachidic (eicosanoic)	0.4
lignoceric (tetracosanoic)	0.2

Unsaturated

oleic (cis-9-octadecenoic)	43.4
linoleic (cis-9-, cis-12-octadecadienoic)	39.1

Fatty Acid	United States				Germany
	1	2	3	4	5
12:0					0.006
14:0					0.064
16:0	11.5	11.1	9.4-13.3	11.1-12.8	11.3
18:0	2.2	2.0	1.2-11.5	1.4-2.6	2.3
18:1	26.6	24.1	17.0-49.1	22.6-36.0	26.9
18:2	58.7	61.9	36.4-70.8	48.9-60.9	56.3
18:3	0.8	0.7			2.7
20:0					0.4

- corn gluten meal and feed (weight percent):

Chemical and Mineral Composition of Corn Gluten Feed and Corn Gluten Meal (Screw Press)

Constituent	Corn Gluten Feed %	Corn Gluten Meal %
protein (N x 6.25)	24.8	42.9
fat	2.6	2.0
fiber	7.8	3.9
N-free extract	49.8	40.1
ash	6.4	2.5

*High oil corn generally contains a larger percentage of oleic and a smaller percentage of linoleic than conventional corn oil.

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- comments:

  --corn gluten feed is relatively high in fiber composition, restricting its use somewhat in poultry feeds; with other amendments is widely used for dairy cows; somewhat non-palatable to swine.

  --corn gluten meal contains less fiber than corn gluten feed; is deficient in lysine and tryptophane; is used in swine rations; is somewhat non-palatable to cattle.

Agronomy:

- high oil corn is currently commercially grown on a very small scale (1,000 to 2,000 acre/year) in the southern U.S. High oil corn has not been bred to the extent of conventional corn in terms of adaptability, disease resistance, etc. In addition, agronomic practices which might be unique to growing high oil corn require attention. For instance, the enlarged embryo of high oil corn apparently requires that the seed be handled carefully in order to avoid decreases in germination. The following descriptive agronomic information refers to the growth of conventional corn and must be appropriately qualified.
- exhibits wide diversity of vegetative types and is adapted to a wide range of environmental conditions.
- geographical range--40°S to 58°N latitude.
- optimum soil--fertile, well-drained loams, pH 5.5 to 8.0.
- growing season--average 140 days (90 to 120 in northern U.S.; 130 to 150 in central and southern corn belt; 170 to 190 in Atlantic and Gulf coast region).
- generally planted from April to May in U.S. corn belt, February in southern Texas.
- region of greatest production in U.S. has a mean summer daytime temperature of 70° to 80°F, mean night temperature of over 13 C, and a frost-free period of over 140 days.
- generally requires at least 15 in/year precipitation, optimally from 23 to 40 in/year except where irrigated.
- best yields, which are generally approximately 90 percent of conventional corn yields, are obtained when grown on heavily fertilized land, e.g., in Illinois most profitable yield response is achieved with an application of from 160 to 180 lbs/acre N for continuous corn.

Non-Fuel End Products:

- oil--edible products (salad oil, margarine); industrial uses (manufacture of rubber substitutes, soaps, inexpensive paints).
- non-oil products of wet milling include corn starch, sweeteners, gluten feed and meal, CO_2.
- Non-oil products of dry milling include distiller's dry grains, CO_2.

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Cottonseed (Gossypium hirsutum L.)

Botanical Description:

- member of the Malvaceae family
- two probable centers of origin: Indo-China and tropical Africa in the Old World; South and Central America in the New World
- exhibits C_3 photosynthetic pathway
- herbaceous annual in North America; long lived perennial in tropics
- attains height of 2 to 5 ft. at maturity
- Comments:

  --cottonseed and the extracted oil is generally considered a by-product of growing cotton fiber for use in textiles

Chemical Composition:

- kernel*

Constituent	Weight Percent
moisture	7
crude protein	30
oil	30
N-free extract	24
crude fiber	4.8
ash	4.4

*Without hull.

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- oil content (weight percent)

Fatty Acid	Weight Percent
14:0	<0.1
14:0	0.8
16:0	22
16:1	0.64
18:0	2.3
18:1	17.3
18:2	55
18:3	0.56
20:0	<0.5
20:1	<0.5
22:0	<0.5
22:1	<0.5
24:0	<0.5

- meal

	Composition (percent weight)					
				Carbohydrate		
Process	Moisture	Crude Fat	Crude Protein	Nitrogen-Free Extract	Fiber	Ash
	%	%	%	%	%	%
Hydraulic	7.6	5.1	41.2	--	--	--
Screw press	4.8	3.7	43.0	--	--	--
Solvent extraction	7.6	0.8	42.4	--	--	--
Prepress solvent extraction	--	0.1-2.3	39.6-45.7	--	--	--
Screw press	4.8-9.9	3.5-9.9	39.2-49.6	23.4-34.5	7.3-15.5	5.1-8.8

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- comments

  --relative amounts of oil, protein, and gossypol in seed are affected by environmental and genetic factors

  --gossypol is the phenolic pigment in cottonseed, composing 0.4 to 1.4 percent of the kernel by weight; it is an anti-oxidant and polymerization inhibitor; for livestock feeding purposes, meal must contain no more than 0.04 percent gossypol

  --cottonseed meal is considered as a good protein supplement for dairy cows, beef cattle and sheep; there are limitations to its use in swine and poultry feed.

Agronomy:

- geographical range--to 37° north latitude
- optimum soils--grows on wide range of soils, from sands to heavy clays, pH 5.2 to 8.0; best on mixtures of clay and sandy loam with adequate organic matter, well-drained
- growing season--180 to 200 frost-free days
- optimum temperature--for germination and early growth, 60°F (minimum), 100°F (maximum), 91°F (optimum); for flowering plants, 90° to 97°F; highest U.S. cotton yields in areas where means July temperature averages 80° to 82°F
- water requirement--in U.S., limited to areas with 16 to 20 in/year or more of rainfall, if not irrigated
- best growing region in U.S., in terms of yield and quality are Mississippi Delta, and irrigated valleys of the southwest.

Non-Fuel End Products:

- oil-margarine, salad oil, cooking oil, soap manufacturing
- hulls-cattle roughage
- meal-livestock feed (see chemical composition)

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Crambe (Crambe abyssinica Hochst)

Botanical Description:

- member of Cruciferae family
- exhibits C_3 photosynthetic pathway
- erect annual herb
- maximum height approximately 23 to 35 in.

Chemical Composition:

- seed (without "pod")
  --approximately 35 percent oil by weight

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- oil

--Fatty Acid	Weight Percent
Saturated	
palmitic (hexadecanoic)	2
stearic (octadecanoic)	1
arachidic (eicosanoic)	1
behenic (docosanoic)	2
Unsaturated	
palmitoleic (cis-9-hexadecenoic)	0.3
oleic (cis-9-octadecenoic)	17
erucic (cis-13-docosenoic)	40-60
linoleic (cis-9,cis-12, octadecadienoic)	7
linolenic (cis-9,cis-12,cis-15-octadecatrienoic)	10

--Fatty Acid	Weight Percent
14:0	0.1
16:0	1.7-2.0
16:1	0.3-0.4
16:3	0.1-1.0
18:0	0.4
18:1	16.7-16.9
18:2	7.8-8.6
18:3	6.4-6.9
20:0	0.5-1.3
20:1	2.9-3.2
20:2	0.2
22:0	2.0-2.7
22:1	55.7-57.2
22:2	0.8
24:1	1.4-2.9

- meal (percent dry weight)

crude protein	49.8
crude fat	5.3
crude fiber	4.6
N-free extract	34.1
ash	6.3

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- comments

  --meal may be used as a feed supplement provided thioglucosides (9 to 11 percent) are removed.

Agronomy:

- geographical range--cool season crop adapted to north central and northwest states (wheat growing areas); may have potential as winter crop in Texas
- fertilizer requirements and cultural practices in general, similar to those of small grains; usually responds to an application of 50 to 75 lbs. nitrogen/acre
- dry and/or irrigated crop; yields enhanced under irrigated conditions
- growing season--approximately 90 to 100 days, but may vary considerably; planting should be delayed until danger of severe freeze is past
- optimum soils--medium light to heavy soils with good drainage
- organized U.S. field studies initiated in 1957; has been grown as oilseed crop in Canada, Montana, Illinois, North Dakota, Indiana, Kentucky, Oregon, Washington

Non-Fuel End Products:

- oil--potential use in plasticizers, rubber additives, waxes, etc.
- meal--feed components, in plywood adhesives.

Flaxseed (Linum usitatissimum L.)

Botanical Description:

- member of Linaceae family
- probably originated in the Mediterranean region
- exhibits C_3 photosynthetic pathway
- herbaceous, but woody-stemmed, annual; both winter and spring planted cultivars exist; cultivars grown for oil production generally differ from those grown for fiber
- at maturity, oil seed flaxes, which range from 15 to 30 in. in height, are shorter and more branching than fiber flaxes. Fiber in seed flax is short, harsh, and generally not used for production of fine yarn
- seeds usually brown, although yellow, mottled, green-yellow and black-seeded cultivars exist
- most U.S. cultivars belong to wilt-resistant, short fiber type

Chemical Composition:

- seed*

Constituent	Weight Percent
water	6.2
protein	24.0
fat	35.9**
carbohydrate	30.3

*Without fruit hull.

**Seeds generally range from 32 to 44 percent oil (dry weight).

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- oil (weight percent)

--Fatty Acid	Range of Values
Saturated	
palmitic (hexadecanoic)	4-7
stearic (octadecanoic)	2-5
arachidic (eicosanoic)	0.3-1
Unsaturated	
oleic (cis-9-octadecenoic)	12-34
linoleic (cis-9,cis-12-octadecadienoic)	17-24
linolenic (cis-9,cis-12,cis-15-octadecatrienoic)	35-60

--Fatty Acid	Range of Values
16:0	6.1-7.0
16:1	0.1
18:0	3.2-5.8
18:1	14.7-39.0
18:2	14.2-18.8
18:3	48.8-59.8

- flaxseed meal (weight percent)

	Solvent-Extracted (%)	Screw-Pressed (%)
crude protein	36.0(a)	34.0(a)
crude fat	0.5(a)	3.5(a)
crude fiber	9.5(b)	10.0(b)
N-free extract	33.0(a)	32.0(a)
ash	6.5(b)	--

- comments:

  --meal can be used as protein concentrate for ruminants (cattle and sheep); meal is deficient in lysine and methionine and is not suitable as the sole source of protein for swine or poultry

(a) minimum

(b) maximum

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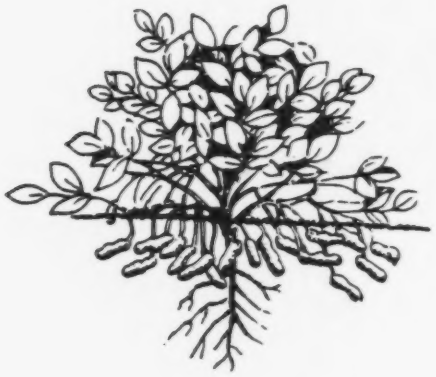
Agronomy:

- geographical range--grown as summer crop in north central U.S. (North Dakota, Minnesota, South Dakota); winter crop in Texas, Arizona, California, Mexico
- optimum soils--best on well drained, medium to heavy soils, especially silt loams, clay loams, silty clays; light soils unsuited, especially where rainfall is deficient
- fertility requirements--relatively low requirement for fertilizer vs. other cereals; exhibits low response to fertilizer
- growing season--varies from 100 to 120 days for spring-planted (April to June) cultivars to 190 to 220 days for winter-sown (November to December) cultivars
- moisture requirements--generally grown where precipitation is 15 to 30 in/year, under irrigation in drier climates
- temperature requirements--grows best in moderate to cool temperatures throughout the growing season
- grows particularly well under late planting conditions, so can be used as an emergency crop when weather or other factors delay planting of another crop

Non-Fuel End Products:

- oil--in paints, varnishes, linoleum manufacture, oil cloth, printer's inks, soaps, etc. (edible in some countries, not in U.S.)
- protein meal--livestock feed (see chemical composition)
- fiber from straw--high grade papers

Peanut (Arachis hypogaea L.)



Botanical Description:

- member of Leguminosae family
- indigenous to South America
- exhibits C_3 photosynthetic pathway
- low, herbaceous annual with central, upright stem
- two basic morphological types, "bunch" and "runner"; pods form in bunches at base of plant in bunch, and are scattered along prostrate branches in runner types
- flowers form above ground and upon withering, stems elongate and bend downward, forcing the ovary underground where the seed matures

Chemical Composition:

- kernel* (weight percent)

Constituent	Range	Average
moisture	3.9-13.2	5.0
protein	21.0-36.4	28.5
lipid	35.8-54.2	47.5
crude fiber	1.2-4.3	2.8
N-free Extract	6.0-24.9	13.3
ash	1.8-3.1	2.9

*Without shell.

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• oil (weight percent)

--Fatty Acid	Variety	
	Spanish	Virginia
Saturated		
palmitic (hexadecanoic)	8.2	8.3
stearic (octadecanoic)	6.2	4.9
arachidic (eicosanoic)	4.0	3.3
lignoceric (tetracosanoic)	3.1	2.6
Unsaturated		
oleic (cis-9-octadecenoic)	52.9	60.0
linoleic (cis-9,cis-12, octadecadienoic)	24.7	21.6

--Fatty Acid	Weight Percent
<14	<0.1
14:0	<0.1
16:0	6.0-15.5
16:1	<1.0
18:0	1.3-6.5
18:1	36-72
18:2	13-45
18:3	<1.0
20:0	1.0-2.5
20:1	0.5-2.1
22:0	1.5-4.8
22:1	<0.1
24:0	1.0-2.5

• meal (weight percent)

MAIN COMPONENTS OF PEANUT MEALS

Type of meal	Composition					
	Dry matter %	Crude protein (Nx6.25) %	Oil %	Crude[(a)] fiber %	Nitrogen-free extractives %	Ash %
Peanut cake or cake meal (decorticated)* (screw- or hydraulic-pressed)	88-94	39-51	5.0-10	4.6-7.0	18-27	4.0-6.0
Peanut cake or cake meal (undecorticated)* (screw- or hydraulic-pressed)	89-93	30-35	9.0-10	22-24	21-22	5.0-6.0
Extracted peanut meal (decorticated)*	88-94	49-57	0.6-3.0	4.0-5.7	22-29	4.9-6.0
Extracted peanut meal (undecorticated)*	92	32	1.9	25	29	4.3
Peanut flour (extracted or pressed)	92-96	50-66	0.5-10	2.0-3.2	21	3.6-4.6

(a) A product containing about 14% fiber is sometimes referred to as "semicorticated".
*Decortation refers to deshelling of the peanut.

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- comments

  --decorticated peanut meal is a valuable supplementary protein concentrate for all classes of livestock; undecorticated cake, high in fiber, is fed only to ruminants; for poultry and swine, meal deficient in methionine, cystine, lysine, and tryptophan

Agronomy:

- geographical range--growing regions have frost-free period of 200 days or more
- optimum soils--growing on well-drained, light, sandy-loam soils promotes (1) harvesting without injury or loss of yield, (2) penetration of the stems bearing fertilized ovules into the soil surface, and (3) well formed pods; optimum pH--5.8 to 6.2
- fertility requirements--has marked ability to utilize fertilizer residues not removed by previous crop; requires abundant potassium and moderate phosphorus; because the plant fixes nitrogen, amendments are not generally necessary
- growing season--ranges from 110 to 150 days depending on variety
- moisture requirements--optimum in regions receiving 42 to 53 in/year; sometimes grown under irrigation

Non Fuel End Products:

- oil--edible oil, peanut butter, salted peanuts, etc.
- protein meal or cake--animal feed (see chemical composition)
- shells--boiler fuel to generate steam for electricity to operate shelling plants; mulch, fertilizer-filler.

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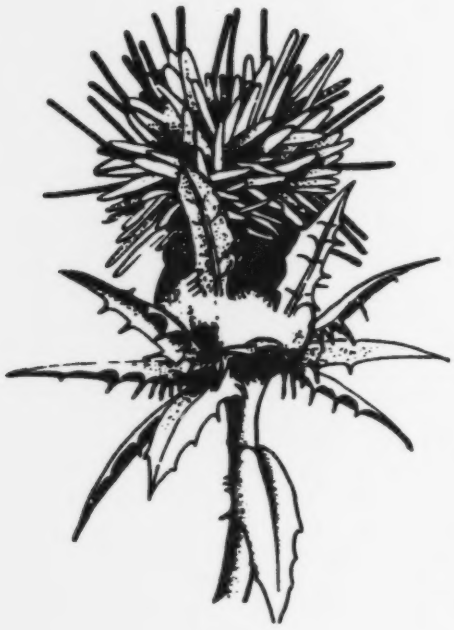
Safflower (Carthamus tinctorius L.)



Botanical Description:

- member of Compositae family
- native to India
- exhibits C_3 photosynthetic pathway
- herbaceous summer or winter annual
- at maturity, 1 to 4 ft. tall, erect, and branched at the top
- head inflorescence, 0.5 to 1.5 in. in diameter, with white, yellow, orange, or red florets.

Chemical Composition:

- seed (weight percent)

oil	30-36
protein	10.8-16.8
hull	38-45

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- oil (weight percent)

Fatty Acid	1	2	3	4
Saturated				
myristic (tetradecanoic)	--	tr	tr	tr
palmitic (hexadecanoic)	--	6.4	3-6	8
stearic (octadecanoic)	--	3.1	1-4	3
arachidic	--	0.2	tr-0.2	tr
Total	5.0-6.7	9.7	5-10	11
Unsaturated				
oleic (cis-9-octadecanoic)	14.7-17.3	13.4	13-21	13
linoleic (cis-9, cis-12-octadecadienoic)	76.6-79.0	76.9	73-79	75
linolenic (cis-9, cis-12, cis-15-octadecatrienoic)	0.04-0.13	--	tr	1
Total	93.3-95.0	90.3	90-95	89

Fatty Acid	Weight Percent
<14	<0.1
14:0	<1.0
16:0	2-10
16:1	<0.5
18:0	1-10
18:1	7.0-42
18:2	55-81
18:3	<1.0
20:0	<0.5
20:1	<0.5
22:0	<0.5

- safflower meal (decorticated)

Dry Matter	Crude Protein (N x 6.25)	Fat	Fiber	Ash	Nitrogen-free Extract
92.0	36.0	7.6	17.5	7.5	23.5

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- comments

  --safflower oil has the highest linoleic acid content of any known oil; is considered to be an excellent source of pure linoleic acid.

  --safflower meal is considered suitable for feeding to livestock, although lack of palatibility and certain amino acid deficiencies should be taken into consideration when developing feed rations.

Agronomy:

- geographic range--Western Great Plains and Pacific Northwest, generally between 30 and 40°N.
- optimum soils--heavy, clay soils or well drained, sandy loams.
- growing season--spring sown, 110 to 150 days (in California, sown from February 15 to April 20, in other areas, April 10 to May 20); fall sown (warm, irrigated areas such as southern California or Arizona), 200 days.
- well adapted to semi-arid regions; roots may grow up to 12 ft. long in some soils.
- generally replaces small-grain crops in rotations; often is sown on fallowed land in dryland areas, and is irrigated in Arizona and other arid areas.
- safflower grown in semi-arid regions often is not fertilized; in Montana seed and oil yields have been increased by adding 30 to 60 lbs. N/acre; 20 to 30 lbs. P_2O_5/acre.
- crop is well adapted to combine harvesting as it does not lodge, and its seeds do not shatter.
- susceptibility to disease and insect damage has deterred commercialization relative to other oilseed crops.
- when grown in dry climates is noticeably less susceptible to diseases; attacked by several diseases in moist conditions.
- largely self-pollinated, except when many insects are present.

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Non-Fuel End Products:

- oil--margarine, salad oil, shortening, and other edible products;
- also used in the manufacture of alkyd resins, soaps, paints, varnishes, enamel, etc.
- commercial dye is extracted from flowers.

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Soybean (Glycine Max (L) Merrill)

Botanical Description:

- member of Leguminosae family
- indigenous to the Orient; introduced to the U.S. circa 1800
- exhibits C_3 photosynthetic pathway
- herbaceous summer annual
- at maturity, an erect, bushy, leafy plant, approximately 2 to 4 ft. tall depending on cultivar and environments.

Chemical Composition:

- seed* (weight percent)

		Carbohydrate			
Moisture	Crude Protein	Crude Fiber	N-free Extract	Oil or Fat	Ash
6.4	39.1	5.2	25.8	18.7	4.8

*Without pod.

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- oil (weight percent)

Fatty Acid	Range
Saturated	
myristic (tetradecanoic) and lower	tr-0.5
palmitic (hexadecanoic)	7-11
stearic (octadecanoic)	2.6
C_{20} and higher	0.3-3
Total	11-20
Unsaturated	
C_{16} and lower	tr-1
oleic (cis-9-octadecenoic)	15-33
linoleic (cis-9,cis-12-octadecadienoic)	43-56
linolenic (cis-9,cis-12,cis-15-octadecatrienoic)	5-11
Total	83-90

Fatty Acid	Wt. %
<14	<0.1
14:0	<0.5
16:0	7.0-12
16:1	<0.5
18:0	2.0-5.5
18:1	19-30
18:2	48-58
20:0	<1.0
20:1	<1.0
22:0	<0.5

- soybean meal (solvent extracted, ground--weight percent)

crude protein*	52.4
N-free extract	33.8
crude fiber	5.9
ether extract	1.3
ash	6.6

- comments

--crude soybean oil, especially if solvent extraction procedures are used, contains 1.1 to 3.2 percent nonglyceride materials, chiefly phosphatides such as lecithin, which is an important industrial raw material

*Soybean protein contains all the essential amino acids for animal feeds and human foods; lysine content is twice that of sunflower; meal also contains trypsin inhibitor, a growth retardant in some animals--it may be removed from the meal by subjecting the meal to proper heating.

--the amount of oil in soybean seeds varies with environmental conditions such as temperature--seeds generally have a higher oil content when grown in warm environments.

Agronomy:

- geographical range--throughout the U.S.
- optimum soils--broadly tolerant of soils, but grow best in well-drained, medium textured soils, with pH of 6.0 to 6.8
- fertility requirements--when properly nodulated, derive much of their nitrogen through nitrogen fixation; phosphorus and especially potassium must be added based on soil testing
- growing season--5-month minimum for most cultivars; planted May to June in most states; can be double-cropped with small grains
- optimum temperature--mean summer of 75° to 77° F for most cultivars; minimum temperature for most growth processes is approximately 50° F.

Non-Fuel End Products:

- oil--shortening, margarine, salad oils; paints, varnishes, ink, caulking compounds, linoleum
- protein cake or meal--soybean flour for human food; animal feed supplement.

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Sunflower (Helianthus annuus L.)

Botanical Description:

- member of Compositae family
- indigenous to North America
- exhibits C_3 photosynthetic pathway
- herbaceous summer annual
- at maturity, a stout, erect plant, approximately 1.6 to 10 ft. tall depending on cultivar and environment
- head inflourescence composes approximately 50 percent (by weight) of the dry matter of the whole plant; nearly 50 percent (by weight) of the dried head is seed; 20 to 25 percent (by weight) of the seed consists of hull, 75 to 80 percent kernal.

Chemical Composition:

- plant content (weight percent)

			Carbohydrate			
Plant Part	Dry Matter	Crude Protein	Crude Fiber	N-free Extract	Crude Oil or Fat	Ash
Seed**	100	17.9	31.0	20.1	27.7*	3.3
Hull	100	3.1	24.7	65.2	3.8	2.4

*Hulled kernel contains 22 to 61 percent oil.

**Kernel plus hull.

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- oil (weight percent)

Fatty Acid	Range of Values
Saturated	
palmitic (hexadecanoic)	3-6
stearic (octadecanoic)	1-3
arachidic (eicosanoic)	0.6-4
behenic (docosanoic)	tr-0.8
lignoceric (tetracosanoic)	tr-0.4
Total	8.7-14.2
Unsaturated	
oleic (cis-9-octadecanoic)	14-43
linoleic (cis-9,cis-12-octadecadienoic)	44-75
Total	85-91

Fatty Acid	Wt. %
<14	<0.1
14:0	<0.5
16:0	3.0-10
16:1	<1.0
18:0	1.0-10
18:1	14-65
18:2	20-75
18:3	<0.7
20:0	<1.0
20:1	<0.5
22:0	<1.0
22:1	<0.5
24:0	<0.5
24:1	<0.5

- sunflower meal* (with hull)

crude protein**	36.0
N-free extract	28.7
crude fiber	26.5
ether extract	2.1
ash	6.7

*Processing methods employed in extraction of oil affect nutritive quality of residual meals, particularly for non-ruminant animals; maximum amount of hull should be removed prior to oil extraction for high quality meals.

**Sunflower protein is deficient in lysine and to a lesser extent methionine.

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- comments:

  --the amount of oil in the sunflower kernel and the relative quantity of the various fatty acids in the oil greatly reflect the influences of climate, temperature, genetic factors, and the position of the seed in the head influorescence.

Agronomy:

- geographic range--throughout the U.S., especially the northern two-thirds
- optimum soils--wide range of well drained soils; fertile sandy loam to clay loam best
- in the midwest U.S., 50 lbs. nitrogen is added for every 1,000 lbs/acre seed; 15 to 30 lbs. P_2O_5/acre; 20 to 50 lbs. K_2O/acre
- growing season--95 to 100 frost-free days; generally planted in May (April in central latitudes)
- pests (disease, birds, insects) reportedly a major drawback to widespread culture
- generally more drought tolerant then most oilseed crops.

Non-Fuel End Products:

- oil-shortening, cooking, salad oils, margarine, and in soaps, paint
- protein cake or meal--livestock feed supplement (low quality meals containing hull should receive discretion if fed to non-ruminants), fertilizer.

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Winter Rape (*Brassica napus* and *B. campestris* L.)*

Botanical Information:

- member of the Cruciferae family
- exhibits C_3 photosynthetic pathway
- species have both annual and biennial forms
- at maturity, approximately 1.3 to 2.5 ft. in height.

Chemical Composition:

- *B. napus* dry seed**

Constituent	Weight Percent
oil	40-45
protein	26
crude fiber	12

*Most of the U.S. research involves *B. napus*.

**Without pod.

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- oil (weight percent):

Fatty Acid	High Erucic Acid Type	Low Erucic Acid Type
Saturated		
palmitic (hexadecanoic)	2-5	5
arachidic (eicosanoic)	0.5	
behenic (dodosanoic)	1.5	
lignoceric (tetracosanoic)	1.0	
Unsaturated		
oleic (cis-9-octadecenoic)	15	52-55
linoleic (cis-9, cis-12-octadecadienoic)	16	24-31
linolenic (cis-9, cis-12, cis-15-octadecatrienoic)	7	10-13
eicosenoic	0-12	0-2
erucic (cis-13-docosenoic)	54	0-1

Fatty Acid	Commercial Oils: High Erucic: Canadian		Commercial Oils: High Erucic: Brown Sarson	Commercial Oils: Low Erucic: Canadian	Developmental Oils: Low Erucic		Developmental Oils: Zero Erucic	
14:0	--	tr.-1.2	--	0.9-1.2	--	--	0.8	--
16:0	1.7	3-4.9	0.6	4.5-6.0	--	--	5.2	--
16:1	0.1	--	--	--	--	--	--	0.5
18:0	0.7	1.1-2	0.8	1.5-2.1	--	--	1.8	2.4
18:1	20.9	14.3-33.5	12.3	48.3-60.7	73.1	65.9	60.7	63.1
18:2	14.3	11.4-13.6	13.5	18.8-22.0	16.1	19.6	19.4	19.4
18:3	8.1	4.7-23.3	11.3	9.3-10.8	4.1	6.9	10.2	9.0
20:0	--	0.5-0.7	--	0.6-0.8	--	--	0.8	tr.
20:1	13.1	0.8-13.5	13.4	0.4-4.3	--	--	0.7	0.8
20:4	--	tr.-0.4	--	tr.-0.2	--	--	tr.	--
20:5	--	tr.-0.4	--	tr.-0.9	--	--	tr.	--
22:0	--	--	--	0.1-0.2	--	--	0.8	--
22:1	41.1	20.1-54.2	48.1	0.1-5.1	--	--	0.1	0
24:0	--	0.1-1.4	--	0.2	--	--	tr.	--

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- meal (weight percent):

Type of Processing	Moisture %	Ash %	Crude Protein %	Digestible Crude Protein %	Nitrogen-free Extract %	Crude Fiber %	Crude Oil %	Total Digestible Nutrients %	Starch Equivalent %
Solvent extraction	--	7.3	35.1	--	31.3	13.4	2.0	--	--
Solvent extraction	10.7	7.3	36.9	30.7	32.7	9.3	3.1	60.3	53.9
Press	11.6	6.9	30.9	26.5	30.0	9.0	11.6	73.5	--
Solvent extraction	11.4	7.0	34.2	--	34.7	11.4	1.3	--	--
Press	11.3	7.4	34.7	28.5	30.3	9.7	6.6	63.3	--
Press	8.6	12.4	35.5	29.4	29.4	8.3	9.6	58.2	59.5

Comments:

- the meal remaining after the oil of various rapeseed cultivars is extracted contains high levels of glucosinolates which may be toxic to livestock.

Agronomy:

- winter rape is currently commercially grown on approximately 6,000 acres in the U.S., all in the state of Idaho. The crop is the subject of various research efforts including determination of production costs, development of high yielding varieties, and varieties which require a shorter season.
- geographic range--areas which can support soft red winter wheat, i.e., below 42°N latitude; southwest and southeast are considered potential growing areas in the U.S.
- optimum soil--fertile loams; however winter rape reportedly survives well on marginal lands; in Idaho, is often grown on summerfallowed lands.
- growing season--winter rape cultivars currently available require planting in early August, and harvest in late July or August of the next year. However, some cultivars mature in as little as 90 days depending on environmental conditions.
- winter rape reportedly can grow with limited moisture, exhibiting efficient water use; in addition, precipitation is more evenly distributed during Idaho winters vs. summers.
- is currently grown on dry land with essentially no added fertilization.

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Non-Fuel End Products:

- oil--high erucic acid oil is not considered edible in many countries, including the U.S.; industrially used in the manufacture of erucic and behenic acids for use as lubricant additives and other purposes.

- meal--ruminants (cattle and sheep) are reportedly less susceptible to toxic effects of meal than other classes of animals; use in feed for pigs and poultry is somewhat restricted.

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Inedible Animal Fats

- inedible animal fats are generally by-products of the meat packing industry.
- primary inedible animal fats are the tallows and greases.
- inedible greases and tallows may contain hog, beef, or mutton fat; greases and tallows are generally defined in terms of hardness, not origin.
- grease is defined as an inedible animal fat with a titer* less than 40°C; inedible tallow has a titer greater than 40°C.
- most tallow is rendered from beef fat (cattle slaughter provides over 75 percent of total tallow production); grease is obtained mainly from pork fat.
- the process of separating animal fat from tissue and cellular structure by the application of heat, pressure, solvent, or a combination of these is termed rendering.
- Types of inedible animal fats include:

  White grease--similar to lard in appearance but has low free fatty content; produced from material which would normally make edible lard but for various reasons is unsuitable for edible purposes; white grease is sterile and may be refined to an edible product even though it is rendered from inedible materials; in order to comply with government regulations packing houses denature white grease by adding petroleum distillates to the vessel in which rendering occurs; in the past, has been exported to Europe where it is refined and sold as food.

  Yellow grease--yellow colored when solid; lower quality than white grease; generally made from the darker colored portions of animals; contains up to 15 percent free fatty acids; small-scale rendering houses may produce all grease materials together and market the product as yellow grease.

  Brown grease--dark in color, lowest grade of packing house grease; made from fats from catch basins which generally contain beef, hog, and mutton fat; also from floor sweepings and recovered fat from tankage.

  Glue grease--by-product of glue manufacturing.

  Bone grease--by-product of processing bones for gelatin, glue, etc.

---

*Temperature at which a sudden rise in temperature is observed which is resultant of the liberation of the latent heat of fusion when molten fatty acids are cooled and begin to solidify.

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Fleshing grease--fatty material obtained from trimming and cleaning fresh hides and pelts.

House grease--from waste cooking (restaurants, etc.)

Garbage grease--waste fat recovered via steam rendering or solvent extraction of food garbage.

- packing house grease is produced in several grades, according to color, titer, free fatty acid content,** and MIU† content:

Standard Grades for Greases

Grade	Min. Titer (°C)	Max. FFA (%)	Max. FAC Color	Max. MIU (%)
Choice White	37.0	4	11	1
White A	37.0	8	15	1
White B	36.0	10	19 or 11C	2
Yellow	36.0	15	37	2
House	37.5	20	39	2
Brown	38.0	50	None	2
No. 1 Glue or Fleshing	37.0	15	15	2
No. 2 Glue or Fleshing	37.0	40	21	2

Chemical Composition:

- beef tallow (weight percent)

Fatty Acid	Range
14:0	3-6
16:0	25-37
18:0	14-29
18:1	26-50
18:2	1-2.5

Non-Fuel End Products:

- Soap making, fatty acid production.

**Fats are hydrolyzed to free fatty acids and glycerol in the presence of water or steam; the reaction is catalyzed by acid and enzymes.

†Combined content of moisture, insoluble impurities, and unsaponifiable material.

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APPENDIX B

ECONOMIC INFORMATION ON
VEGETABLE OILS AND ANIMAL FATS

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APPENDIX B

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APPENDIX B

ECONOMIC INFORMATION ON VEGETABLE OILS AND ANIMAL FATS

This Appendix contains "non-technical" information and data on vegetable oils and their by-products, and animal fats. Data on total production, location of production, yield-per-acre, current utilization trends, production costs, and price comparisons are included. Also included is brief descriptive information on industry trends and processing methods for soybeans, cottonseed, peanuts, sunflowers, and animal fats. Maps of oilseed production areas and processing facilities are provided to the extent that data are available.

The information is assembled such that comparisons can be made among the various oilseeds and animal fats. This format differs slightly from that used in presenting the technical data, where the information is presented on a commodity-by-commodity basis.

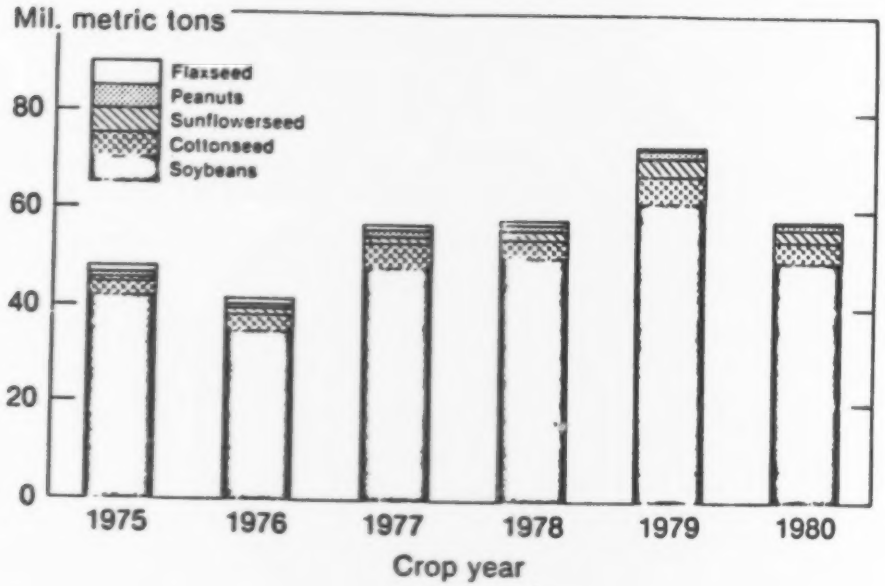
Data users should remember that this information basically presents a summary of much more detailed statistics, many of which are available from U.S. Department of Agriculture periodicals and special reports.

Production and Utilization

Trends in U.S. oilseed production for soybeans, cottonseed, sunflower seed, peanuts, and flaxseed from 1975 to 1980 are indicated in Figure B-1. Soybeans account for over 86 percent of U.S. oilseed production, followed by cotton seed (7.0 percent), sunflower seed (3.9 percent), and peanuts (2.1 percent).

Table B-1 indicates a summary of average U.S. oilseeds production and price data for 1979 and 1980. This table includes oil and meal production per acre, oil and meal prices, and total value of oil and meal per acre.

It is important to note the relationship between oilseed oil and meal production. For products such as soybean, peanuts, and



Source: U.S. Department of Agriculture.

FIGURE B-1. U.S. OILSEED PRODUCTION

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TABLE B-1. SUMMARY OF OILSEEDS PRODUCTION AND PRICE 1979-1980

Oilseed	Average Yield 1979-1980 (Lbs/Acre)	Total US Production (1,000 Tons)	Lbs of Oil/Acre	Gallons of Oil/Acre[d]	Lbs of Meal/Acre	Price of Oil (¢ per Gallon)	Price of Meal ($ Per Ton)	Total Farm Value of Oilseed ($ Per Acre)
Soybean	1767	61,276	316	41.1	1393	198	215.77	213
Peanut	2122	1566	673	87.4	889	261.5	232.26	464
Sunflower	1182	2775	473	61.4	655	225.0	112.25[b]	120
Safflower[a]	1495	215	493	64	897	354.0	175.00	NA[c]
Cottonseed	791	5069	126	16.4	359	214.5	200.63	48
Rapeseed[a]	2000	6	855	111.0	1150	354.0	NA[c]	NA[c]
Flaxseed	709	282	253	32.8	469	220.5	171.88	86

Source: BCD calculations from U.S. Department of Agriculture statistics.

(a) 1980 only. This high yield is not expected in large-scale production.

(b) 1980 - 1981 average price.

(c) N.A. - Not available.

(d) One gallon = 7.7 lbs.

sunflowers, the oil is generally assumed to be the "primary" product and the meal a secondary or "by-product". Nevertheless, the "by-product" meal may actually have a higher value per acre of oilseed production than the vegetable oil (e.g., soybeans). Cottonseed presents a different situation in that cottonseed itself is a by-product of producing cotton for fiber. Because of the dual product capabilities of oilseeds, it becomes somewhat complex to allocate production costs to each product. This will be discussed in more detail in a later section.

In terms of vegetable oil production per acre, rapeseed is the leading crop, with an average of 111 gallons per acre, followed by peanuts (87 gallons per acre), and sunflower (61 gallons per acre). Note, however, that rapeseed production is very minor and relatively untested in the United States. Soybeans produced an average of 41 gallons of oil per acre in 1979/1980, but are higher than any other oilseed crop in terms of meal production per acre (1393 pounds per acre for these two years).

The supply and demand for edible and inedible tallow from 1970/1979 is indicated in Table B-2. Inedible tallow, would be the most likely form of animal fat for diesel fuel substitution, because of its high availability and low cost. Inedible tallow production for the year beginning October, 1979, was estimated at slightly over 6.0 billion pounds, or about 86 percent of total tallow production. In times of surplus, soybean oil also has high availability and low cost.

Table B-3 indicates a summary of U.S. production and price of vegetable oils and inedible tallow for 1979, with prices for March, 1981. Together, soybean oil and inedible tallow account for over 85 percent of total U.S. production of seven commodities listed in Table B-3. These data are also depicted graphically in Figure B-2.

Table B-4 indicates the supply and demand for domestically produced U.S. vegetable oils in the United States from 1978 to 1980. Included are data on stocks, imports (which are virtually non-existent), production, exports and shipments, and domestic disappearance.

U.S. stocks of fats and oils as of October 1 for the years 1971-1980, are included in Table B-5. These data, expressed in thousands of gallons except for inedible tallow and grease, include imported oil such as coconut oil, palm oil, and palm kernel oil. Total stocks as of October 1, 1980, were approximately 234 million gallons, of which 67 percent was comprised of soybean oil.

TABLE B-2. TALLOW (INEDIBLE AND EDIBLE) AND GREASES: SUPPLY AND DEMAND, 1970-79

Year Beginning October	Supply						Demand				
	Production			Imports	Stocks, Oct. 1	Total	Exports	Inedible	Edible	Total	Grand Total
	Inedible	Edible	Total								
	Million Pounds										
1970	5,252	550	5,802	7	407	6,216	2,597	2,628	518	3,146	5,743
1971	5,095	523	5,618	7	473	6,098	2,452	2,735	546	3,281	5,733
1972	4,845	481	5,326	2	365	5,693	2,300	2,567	479	3,046	5,346
1973	5,595	556	6,151	8	347	6,506	2,583	2,940	500	3,440	6,023
1974	4,908	557	5,465	12	483	5,960	2,204	2,878	548	3,426	5,630
1975	5,464	528	5,992	16	332	6,340	2,164	3,295	470	3,765	5,929
1976	6,030	530	6,560	6	411	6,977	2,872	3,180	534	3,714	6,586
1977	6,108	795	6,903	6	396	7,305	2,742	3,404	723	4,127	6,829
1978 (1)	6,050	935	6,985	6	436	7,427	2,675	3,377	875	4,252	6,927
1979 (2)	6,075	975	7,050	5	500	7,555	2,700	3,450	900	4,350	7,050
1980											

Source: FOS-297, October, 1979, U.S. Department of Agriculture.
(1) Preliminary.
(2) Forecast.

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TABLE B-3. U.S. PRODUCTION AND PRICE OF VEGETABLE OILS AND INEDIBLE TALLOW

Type	1979 Quantity Produced		Percent of Total Production	March, 1981 Price ($/Gallon)
	Million Lbs	Million Barrels		
Soybean oil	12,105	37.4	56.8	1.80
Inedible tallow	6,075	18.8	28.5	1.16
Cottonseed oil	1,423	4.4	6.7	1.96
Corn oil	791	2.4	3.7	1.81
Sunflower oil	493	1.5	2.3	2.00
Linseed oil	240	0.7	1.1	2.46
Peanut oil	188	0.6	0.9	2.50
Total	21,315	65.8	100.0	N.A.

Source: Fats and Oils Situation, U.S. Department of Agriculture.

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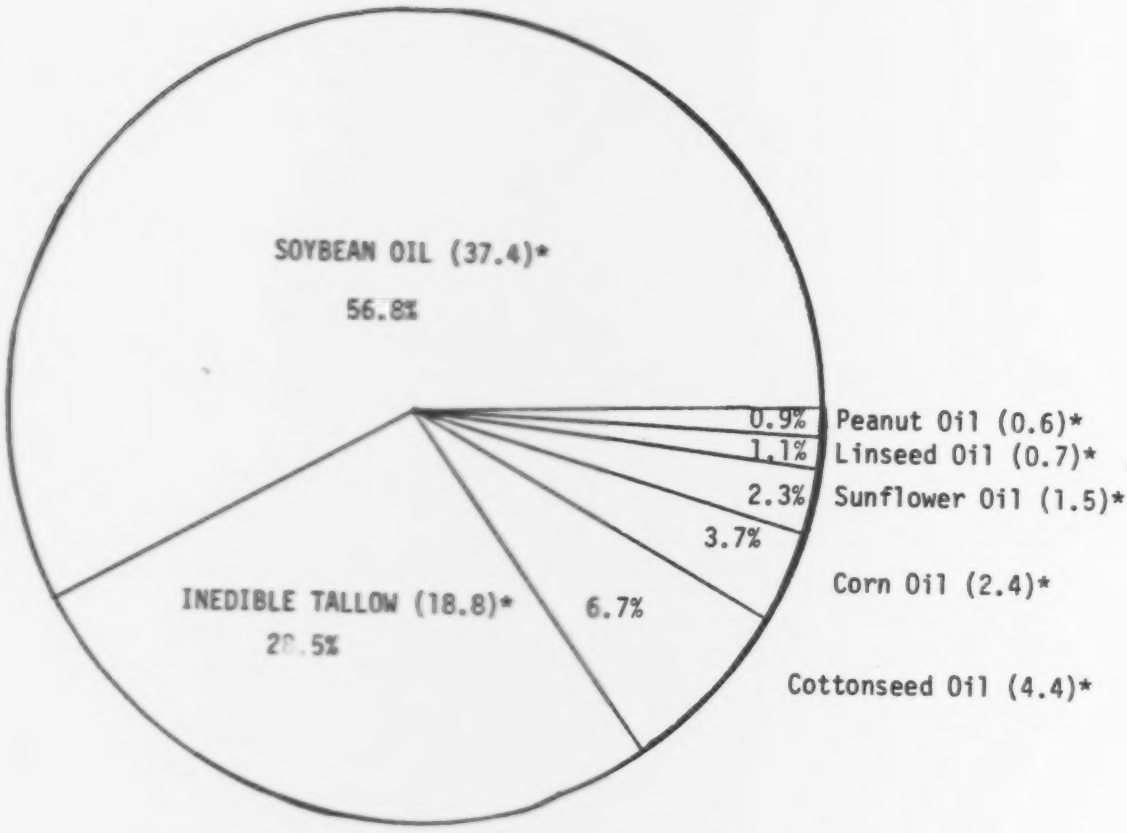

FIGURE B-2. DISTRIBUTION OF U.S. PRODUCTION OF MAJOR VEGETABLE OILS AND INEDIBLE TALLOW (Based on 1979 production data)

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TABLE B-4. SUPPLY AND DEMAND FOR U.S. VEGETABLE OILS IN THE UNITED STATES, 1978-1980(a)

	Corn Oil	Cottonseed Oil	Peanut Oil	Safflower Oil	Soybean Oil	Sunflower Oil
			(million lbs) (b)			
Stocks						
1978	73	85	33	21	729	7
1979	70	86	47	41	776	15
1980	66	122	22	31	1210	108
Imports						
1978	-	-	-	-	-	-
1979	-	-	7	-	-	-
1980	-	-	-	-	-	-
Production						
1978	736	1282	164	125	11,323	254
1979	791	1423	188	100	12,105	494
1980	875	1328	150	100	11,550	719
Exports & Shipments						
1978	125	661	30	25	2,334	90
1979	141	728	20	25	2,690	190
1980	160	800	10	25	1,750	551
Domestic Usage						
1978	613	620	120	80	8,942	154
1979	647	659	193	85	8,981	212
1980	715	550	150	75	9,150	165

(a) Linseed oil not available.
(b) 1.0 gallon = 7.7 lbs.

Source: U.S. Dept, of Agriculture, Fats and Oils Situation, selected issues.

TABLE B-5. UNITED STATES STOCKS OF FATS AND OILS, OCTOBER 1, 1971 - 1980
(Thousands of Gallons)

Product	1971	1972	1973	1974	1975	1976	1977	1978	1979[1]	1980[2]
Inedible Tallow & Grease[3,4]	51,428	49,350	44,286	46,234	49,351	35,974	46,104	44,675	45,065	--
Coconut Oil	14,364	14,763	15,162	16,226	14,231	16,891	18,221	19,285	13,433	20,216
Corn Oil	7,540	9,100	7,410	8,840	6,760	5,330	5,980	9,490	9,100	8,580
Cottonseed Oil	12,220	14,820	14,820	14,300	17,680	13,650	10,270	11,050	11,180	15,860
Soybean Oil	100,490	102,050	67,080	103,220	72,930	162,630	99,710	94,770	100,880	157,300
Palm Oil	4,680	12,090	7,800	11,440	16,510	17,940	17,030	9,620	9,620	5,460
Palm Kernel Oil	3,458	3.192	2,660	3,458	2,660	3,591	6,118	2,394	3,059	5,719
Peanut Oil	3,120	2,340	2,340	2,860	5,720	25,870	22,230	4,290	6,110	2,860
Safflower Oil	3,770	5,070	4,030	1,040	3,250	5,720	3,250	2,730	5,330	4,030
Sunflower Oil	—	—	—	—	—	2,600	—	910	1,948	14,170
TOTAL (Vegetable Oils)	149,642	163,425	121,302	161,384	139,741	254,222	182,809	154,539	158,907	234,195

Source: Fats & Oil: Situation's Outlook, USDA, February 1981, and BCD calculations.

1 Preliminary.

2 Forecast.

3 Tallow is solid; estimate is in equivalent gallons.

4 Includes inedible tallow and choice white grease.

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Table B-6 indicates the domestic utilization of fats and oils in products for civilian consumption in the United States in 1979. The largest uses are in salad and cooking oils (24 percent) and baking and frying fats, or shortening (21 percent). Overall, roughly two-thirds of vegetable oils and animal fats are used in food products, with one-third going to industrial uses, which include primarily fatty-acids, animal feeds, soap, and drying oil products.

Oilseed Production Costs

The cost of producing the major oilseed crops in the United States in 1979 is indicated in Table 7. These costs do not include a return to management and general farm overhead expenses. The addition of general farm overhead and management would increase total production costs for soybeans by approximately $19 per acre, or about nine percent over the $212.74 per acre quoted in Table 7.

The importance of land charges on total production costs should be noted in Table 7. For example, land charges based on the land's current value contribute almost 58 percent of total soybean production costs. In those cases where the land is wholly owned by the farmer, this does not represent an out-of-pocket, or cash expense. However, it would represent a cash expense if the farmer were renting the land or paying interest on a land mortgage.

Total production cost per acre of peanuts are over two and one-half times as great as cotton and soybeans, and over four times greater than sunflower. However, it should be noted that peanut acreage is regulated by Federal allotments, and other devices such as support prices and import and tonnage restrictions. If these restrictions were removed, peanut production costs likely would decline.*

Total estimated production cost per gallon of vegetable oil are estimated before and after deducting by-product credits for the oilseed meal. The by-product credit on the farm value of the oilseed meal was assumed to be 80 percent of the wholesale market price. Also, it should be noted that when the lint value of cotton is deducted from the production cost, along with the cottonseed meal, the farm production cost of cottonseed oil is less than zero.

* Ultimately, peanuts may be produced for about $375-400 per acre and yields might rise in the range of 3000-4000 pounds per acre, from the present average of 2100 pounds per acre. For the near future, peanuts may cost about 20 percent more than sunflower and occupy a complementary geographical range.

TABLE B-6. DOMESTIC USE OF FATS AND OIL IN PRODUCTS FOR CIVILIAN CONSUMPTION, UNITED STATES, 1979

	Million Lbs	Percent of Total
Food Products		
Butter	1,009	5.2
Lard	564	2.9
Margarine	2,524	13.0
Baking and Frying Fats (Shortening)	4,144	21.3
Salad and Cooking Oils	4,689	24.1
Other Edible Uses	377	1.9
Subtotal, Food Products	13,307	68.4
Industrial Products		
Soap	861	4.4
Drying Oil Products	479	2.5
Fatty Acids	2,314	11.9
Animal Feeds	1,313	6.7
Other Industrial Products	1,193	6.1
Subtotal, Industrial Products	6,160	31.6
Total, All Products	19,467	100.0

Source: Calculated by Battelle-Columbus from U.S. Deaprtment of Agriculture Statistics.

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TABLE B-7. COST OF PRODUCING OILSEED CROPS, UNITED STATES, 1979
($ PER ACRE, EXCLUDING MANAGEMENT AND OVERHEAD).

Cost Item	Soybean (1)	Cotton (2)	Peanuts (3)	Sunflower (4)	Flaxseed (5)
Fertilizer	4.67	7.94	25.50	13.35	2.21
Chemicals	11.81	10.99	83.86	14.93	2.04
Fuel and Lubrication	7.90	18.93	29.17	8.12	5.28
Other Variable Costs (6)	33.19	87.70	201.35	39.20	20.19
Machinery Ownership Costs (7)	31.80	45.45	64.98	18.71	25.69
Total Costs, Excluding Land	89.37	171.01	404.86	94.31	55.41
Land Charge, Based on Current Value	123.37	46.74	149.08	39.39	38.08
Total Costs, Including Land	212.74	217.75	553.94	133.70	93.49
Total Costs, Excluding Byproduct Credits, Per Gallon of Oil	4.75	11.58	5.15	1.91	2.63
Total Costs, After Deducting Byproduct Credits (9)	$ 2.48	$ -0- (8)	$ 4.49	$ 1.57	$ 1.81

(1) Lake States and Corn Belt, comprising 61% of U.S. production.

(2) Southern Plain, comprising 43% of U.S. production.

(3) Southeast, comprising 63% of U.S. production. These costs are not typical of fuel-grade peanut production which is likely to be approximately $375-$400 per acre (Dr. J.H. Butler, USDA Southern Energy Center, Tifton, GA., personal communication, 1981). See Appendix D.

(4) North Dakota.

(5) United States, essenially North and South Dakota, and Minnesota.

(6) Including seed, lime, labor, custom operations, repairs, drying, interest on working capital, and ginning (cotton only).

(7) Includes replacement, interest, taxes, and insurance.

(8) When value of cotton lint and meal is deducted from total costs, cottonseed oil production costs at the farm gate are zero.

(9) See Table B-1 for estimated 1979/80 average production and value of byproducts. (This table based only on 1979 values).

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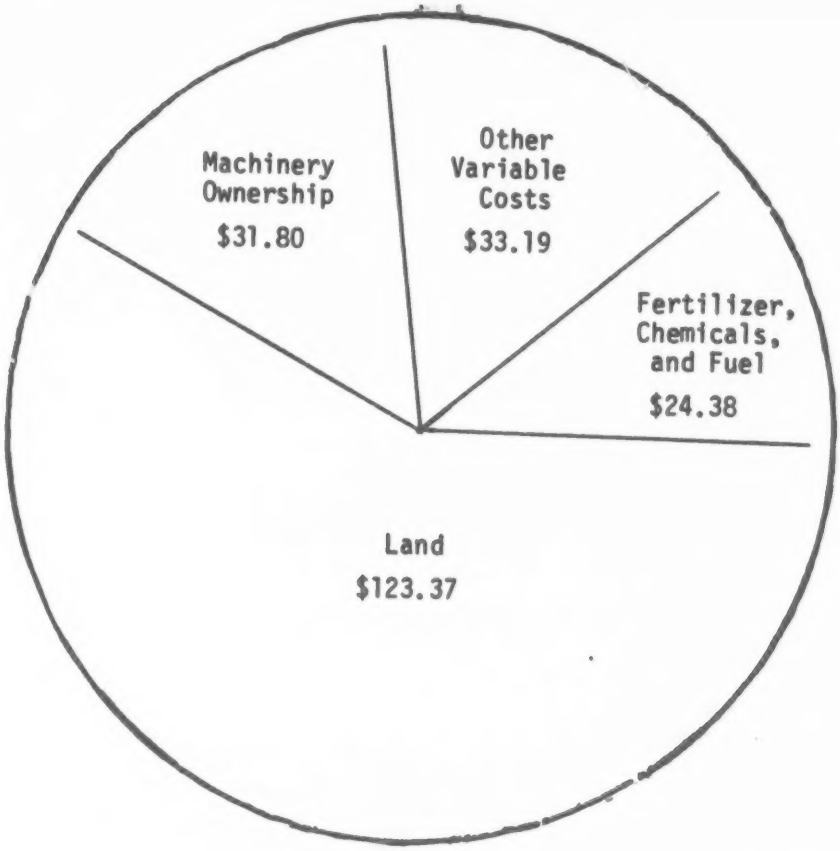

FIGURE B-3. 1979 SOYBEAN COSTS PER ACRE

FIGURE B-4. 1979 SUNFLOWER COSTS PER ACRE

FIGURE B-5. 1979 PEANUT COSTS PER ACRE

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It should be noted that the above estimated production costs are shown for comparison purposes only, and are not necessarily reflective of the market value of the various vegetable oils, as will be noted in the following section.

The contribution of various cost components to soybean, sunflower, and peanut costs are shown graphically in Figures B-3, B-4, and B-5.

There is relatively little information available on rapeseed and safflower production costs in the United States. The available information is summarized in Table B-8, indicating area, yield, production, price, and cost for 1980. These data are based on experimental results in Washington, Oregon, and Idaho. Total production costs per acre (including land but excluding management and overhead) are estimated to be $176 and $162 per acre respectively for winter rape and safflower. Production costs, (excluding by-product credits for oilseed meal per gallon of vegetable oil are estimated at $1.50-$1.69 per gallon for rapeseed oil and $2.31-$2.79 per gallon for safflower oil ($1.19-$1.44 per gallon for safflower oil after deduction of by-product credits).

Price Comparisons for Vegetable Oils, Animal Fats, and Diesel Fats

Diesel fuel prices in current dollars and 1972 dollars are shown in Tables B-9 and B-10, respectively. Average U.S. number two wholesale prices for diesel fuel rose from approximately 32 cents per gallon in 1976, up to 81 cents per gallon in 1980 in current dollars. However, in terms of 1972 prices (current prices divided by implicit price deflators for Gross National Product, with 1972 = 100) diesel fuel has risen from approximately 24 cents per gallon in 1976, up to slightly less than 46 cents per gallon in 1980.

Table B-11 indicates trends in wholesale prices from 1970-1981 for vegetable oils, tallow, and diesel fuel, measured in current dollars. From 1978 up to the current period in 1981, diesel fuel prices have been rising at a faster rate than vegetable oils and inedible tallow. In 1978, the average price of soybean oil was $1.98 per gallon, compared with a diesel fuel price of 37 cents per gallon, resulting in a soybean

TABLE B-8. U.S. WINTER RAPE AND SAFFLOWER: AREA, YIELD, PRODUCTION, PRICE AND COST (1980)

	Winter Rape	Safflower
Area Harvested (Acres)[a]	6,000	287,000
Oilseed Yield Per Acre (lbs) Commercial	2,000	1,495
Total Production (1,000 tons)	6	215
Oil Content (Weight percent of the seed)	40 - 45	30 - 36
Vegetable Oil Production Per Acre		
(lbs)	800 - 900	449 - 538
(Gallons)	104 - 117	58 - 70
Oilseed Meal Production Per Acre (lbs)	1100 - 1200	897
Oil Price		
($ per lb)	0.46	0.46
($ per gallon)	3.54	3.54
Meal Price Per Ton ($)	No Market Price Available	175.00[1]
Production Cost, Including Land, Per Acre ($)	176.00	162.00
Production Cost, Including land, Per CWT ($)	8.80	10.84
Production Cost, Including Land, Per Gallon ($)		
Excluding Byproduct Credit	1.50 - 1.69	2.31 - 2.79
Including Byproduct Credit	Not Available	1.19 - 1.44

(a) Estimate

Source: Battelle Columbus Division estimates and data from "Vegetable Oil as an Agricultural Fuel for the Pacific Northwest", Univ. of Idaho, Agr. Expt. Station Bulletin No. 598; revised, February, 1981.

TABLE B-9. DIESEL FUEL PRICES, CURRENT DOLLARS

	On Farm Diesel Fuel	Chicago Wholesale Prices (Cents per Gallon, Excluding Tax) Distillate No.1	Chicago Wholesale Prices (Cents per Gallon, Excluding Tax) Distillate No.2	US Average No. 2 Wholesale	US Average No. 2 Retail
1970	18	11.25-11.50	10.50-10.75	-	-
1971	19	11.75	11.00	-	-
1972	19	11.75	11.00	-	-
1973	28	15.00	14.00	-	-
1974	41	30.00-34.50	29.00-33.50	-	-
1975	41	28.50-31.50	27.00-32.00	-	-
1976	42	30.75-33.25	30.00-31.50	31.90	34.70
1977	46	37.50-39.00	35.50-37.00	36.10	39.30
1978	48	37.70-39.15	35.50-36.75	37.10	40.20
1979	86	54.40-61.50	50.50-69.00	58.20	62.40
1980	99	83.70-86.50	81.20-83.75	81.20	87.40
May, 1981	118	N.A.	100.50-104.50	N.A.	N.A.

Source: Agricultural Statistics, USDA, various issues; Monthly Energy Review, US DOE, Energy Information Administration, November, 1978, April, 1981; Oil and Gas Journal, The Petroleum Publishing Company, various issues.

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TABLE B-10. DIESEL FUEL PRICES, 1972 DOLLARS

	On Farm Diesel Fuel	Chicago Wholesale Prices (Cents per Gallon, Excluding Tax)		US Average No. 2	
		Distillate No.1	Distillate No.2	Wholesale	Retail
1970	19.68	12.30-12.58	11.48-11.76	-	-
1971	19.79	12.24	11.46	-	-
1972	19	11.74	11.00	-	-
1973	26.49	14.19	13.25	-	-
1974	35.68	26.11-30.02	25.23-29.15	-	-
1975	32.65	22.70-25.09	21.50-25.49	-	-
1976	31.79	23.28-25.17	22.71-23.84	24.15	26.27
1977	32.90	26.82-27.89	25.39-26.46	25.82	28.11
1978	31.99	25.12-26.09	23.66-24.49	24.73	26.79
1979	52.84	33.42-37.78	31.03-42.39	35.76	38.34
1980	55.82	47.19-48.77	45.78-47.22	45.78	49.28
May, 1981	62.10	N.A.	52.90-55.00	N.A.	N.A.

Source: Agricultural Statistics, USDA, various issues; Monthly Energy Review, US DOE, Energy Information Administration, November, 1978, April, 1981; Oil and Gas Journal, The Petroleum Publishing Company, various issues.

TABLE B-11. VEGETABLE OILS, TALLOW, AND DIESEL FUEL PRICES, CURRENT DOLLARS[1]

	Midwestern Mills, Soybean Oil	Southeastern Mills, Cottonseed Oil	Sunflowerseed Oil	Southeastern Mills, Peanut Oil	Minneapolis, Linseed Oil	Chicago, No.1 Inedible Tallow[1]	Midwestern Mills Corn Oil	East Coast, Safflower Oil	Wholesale, No. 2 Diesel Fuel	Soybean Oil/ Diesel Fuel Price Ratio	Tallow/ Diesel Fuel Price Ratio
				($/Gallon)							
1970	.92	1.04	----	1.46	.85	.55	1.27	1.26	---	---	---
1971	.97	1.18	----	1.59	.69	.51	1.52	1.41	---	---	---
1972	.82	.91	----	1.57	.71	.46	1.26	1.46	---	---	---
1973	1.52	1.36	----	1.99	1.12	.95	1.74	1.51	---	---	---
1974	2.76	2.93	----	3.80	3.42	1.17	3.13	2.19	---	---	---
1975	1.96	2.13	----	2.99	3.08	.92	2.49	4.94	---	---	---
1976	1.45	1.84	----	2.43	2.08	1.02	1.99	3.56	.32	4.5	3.2
1977	1.83	1.87	.85	2.29	2.04	1.05	2.36	N.A.	.36	5.1	2.9
1978	1.98	2.07	----	3.26	1.86	1.23	2.77	N.A.	.37	5.4	3.3
1979	2.13	2.36	2.54	2.85	2.21	1.66	2.49	N.A.	.58	3.7	2.9
1980	1.82	1.93	1.96	2.38	2.20	1.10	2.03	3.56	.81	2.2	1.4
12/80	1.74	2.08	2.16	3.78	2.29	1.08	2.16	3.54	.88	2.0	1.2
3/20/81	1.80	1.96	2.00	2.50	2.46	1.16	1.81	3.62	.98	1.8	1.2
5/29/81	1.69	2.04	2.04	2.93	2.54	1.31	1.79	N.A.	1.00	1.7	1.3

(1) Based on reported wholesale vegetable oil and tallow prices per pound; assumes 7.7 lbs per gallon.

(2) Estimated

Source: Fats and Oils Situation, U.S. Dept. of Agriculture, various issues;
Agricultural Statistics, U.S. Dept. of Agriculture, various issues;
Chemical Market Reporter, various issues;
Battelle Columbus Division calculations

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oil/diesel fuel price ratio of 5.4. A similar calculation for the ratio of inedible tallow to diesel fuel resulted in a price ratio of 3.3 in 1978. In 1980, the average soybean oil price had declined to $1.82 per gallon, while the average wholesale price of number two diesel fuel had risen to 81 cents per gallon. This resulted in the soybean oil/diesel fuel price ratio of 2.2 in 1980. Similarly, the ratio of inedible tallow to diesel fuel price ratio has fallen from 3.3 in 1978 to 1.4 in 1980. As of mid-1981, the soybean/diesel fuel price ratio is estimated at approximately 1.7, while the tallow/diesel fuel price ratio is estimated at approximately 1.3.

Table B-12 indicates the price trends for vegetable oils, tallow, and diesel fuels in terms of constant 1972 dollars. Figure B-6 indicates graphically trends in soybean oil, inedible tallow and diesel fuel prices from 1970 through 1981. Figure B-7 indicates the ratio of soybean oil and tallow prices to wholesale diesel fuel prices over the same period.

The above data for those products (soybean oil and inedible tallow), which comprise over 85 percent of all vegetable oils and animal fats indicate that strictly on the basis of price comparisons, soybean oil and tallow are becoming more price competitive with diesel fuel. These price comparisons are based only on a volume basis, and do not account for differences in heating value, burning characteristics, and other important technical factors discussed elsewhere in this report. If today's price ratios were to remain unchanged, it would not be economical to substitute soybean oil and tallow for diesel fuel in the absence of government subsidies.

Additional processing or refining that may be necessary to enhance the "burnability" of vegetable oils and tallow would, of course, further increase their price relative to diesel fuel.

Marketing Margins

Marketing margins consist of the cost of various marketing functions necessary to process a farm commodity into a finished food product on the grocery shelf. A 1977 study by the U.S. Department of Agriculture indicated the components of price spreads for a 24-ounce

TABLE B-12. VEGETABLE OILS, TALLOW, AND DIESEL FUEL PRICES, 1972 DOLLARS[a]
(DOLLARS PER GALLON)

	Midwestern Mills Soybean Oil	Southeastern Mills Cottonseed Oil	Sunflower-Seed Oil	Southeastern Mills Peanut Oil	Minneapolis Linseed Oil	Chicago No.1 Inedible Tallow	Midwestern Mills Corn Oil	East Coast Safflower Oil	Wholesale No. 2 Diesel Fuel
1970	1.01	1.14	--	1.34	.93	.60	1.39	1.38	--
1971	1.01	1.23	--	1.66	1.04	.53	1.58	1.47	--
1972	.82	.91	--	1.57	.71	.46	1.26	1.46	--
1973	1.44	1.29	--	1.88	1.06	.90	1.65	1.43	--
1974	2.46	2.55	--	3.31	2.98	1.02	2.72	1.91	--
1975	1.56	1.70	--	2.38	2.45	.73	1.98	3.93	--
1976	1.10	1.40	--	1.84	1.57	.77	1.51	2.69	.24
1977	1.31	1.34	.61	1.64	1.46	.75	1.69	NA	.26
1978	1.32	1.38	--	2.17	1.24	.82	1.85	NA	.25
1979	1.31	1.49	1.56	1.75	1.36	1.02	1.53	NA	.36
1980	1.03	1.09	1.11	1.34	1.24	.62	1.14	2.01	.46
12/80	.98	1.17	1.22	2.13	1.29	.61	1.22	2.00	.48
3/20/81	.96	1.05	1.07	1.33	1.31	.62	.97	1.93	.52
5/29/81	.89	1.07	1.07	1.54	1.34	.69	.94	NA	.62

(a) Based on reported wholesale vegetable oil and tallow prices per pound; assumes 7.7 pounds per gallon.

Source: Fats and Oils Situation, U.S. Department of Agriculture, various issues.
Agricultural Statistics, various issues, and BCD calculations.

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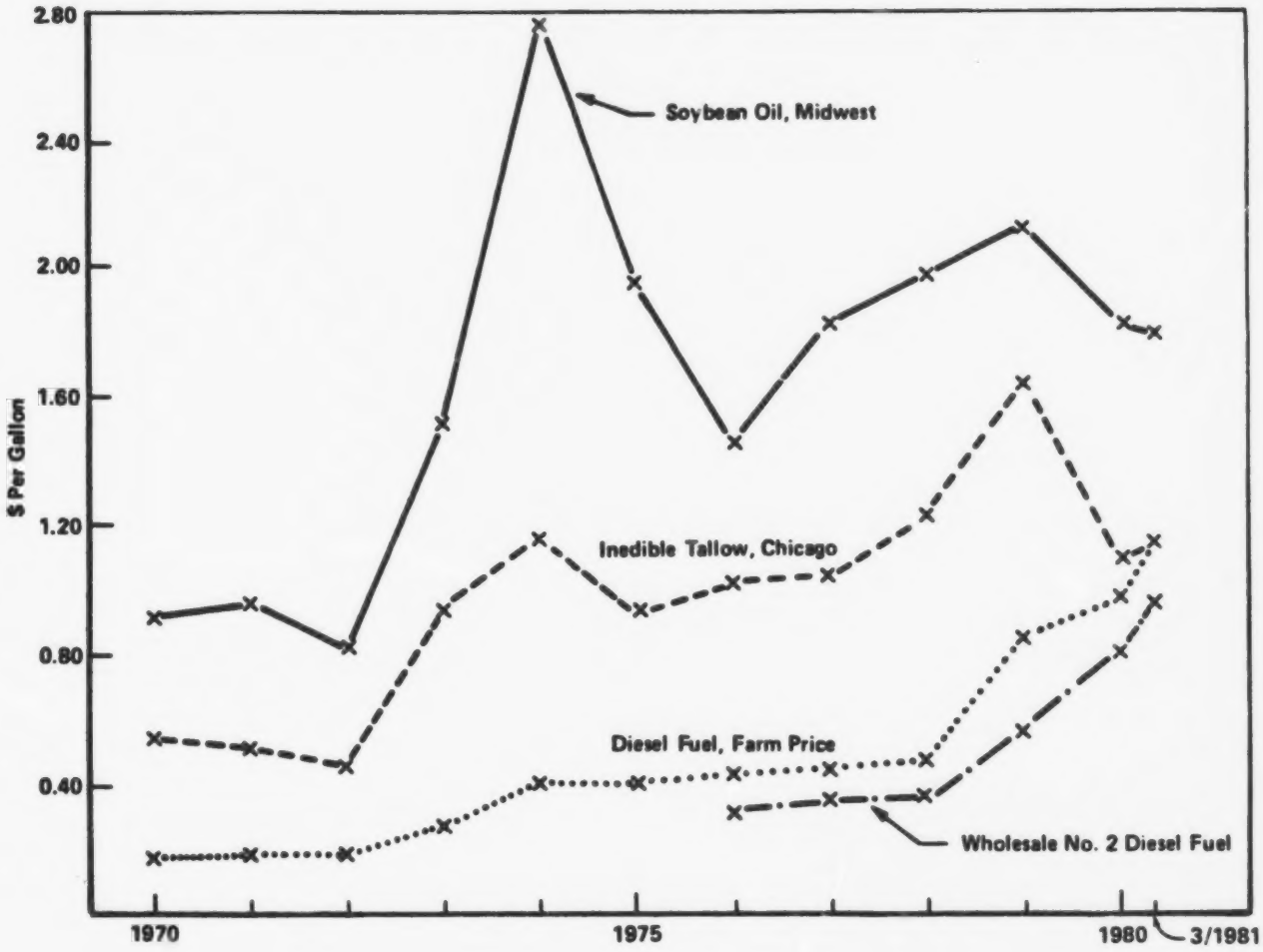

FIGURE B-6. SOYBEAN OIL, TALLOW, AND DIESEL FUEL PRICES 1970-1981

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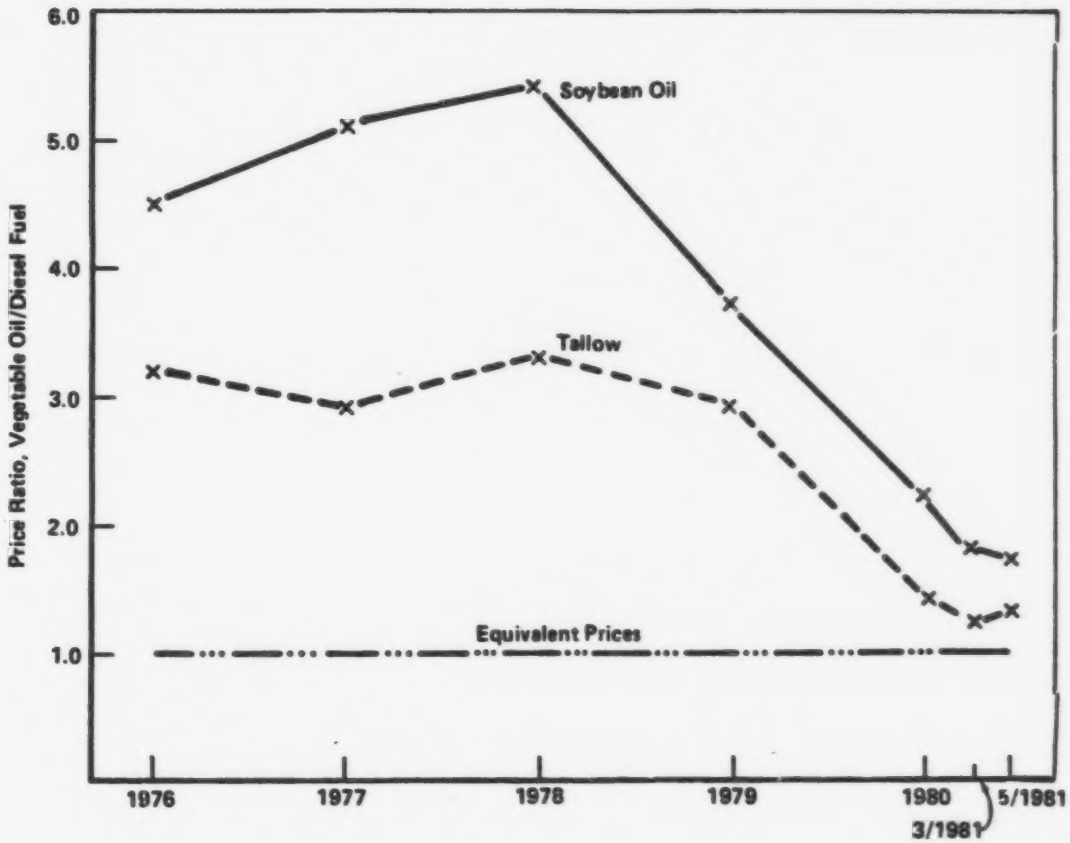

FIGURE B-7. RATIO OF SOYBEAN OIL AND NO. 1 INEDIBLE TALLOW PRICES TO PRICES PAID BY FARMERS FOR DIESEL FUEL, 1970-1981

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bottle of cooking and salad oil produced in 1975.* These data indicate that for a retail price of approximately $1.16 per 24-ounce bottle, the farm value of the soybeans used to produce the oil accounted for only 35 cents or about 30 percent of the retail price (see Table B-13).* Note in Table B-13 that assembly and storage costs plus oilseed crushing account for only about 4.8 cents per 24-ounce bottle of cooking and salad oil. These functions are all that presumably would be necessary if the soybean oil were diverted to fuel use rather than food use. Oil refining, manufacturing, wholesaling, and retailing would not necessarily be similar to those used in the food industry. Presumably, these functions would be more analogous to those used in petroleum refining.

At any rate, the assembly and storage and oilseed crushing costs for cooking and salad oil were approximately 25 cents per gallon in 1975, (about $0.38 per gallon in current dollars), assuming a proportionate increase in margins associated with a 24-ounce bottle. There is no readily available information to indicate how much assembly and storage and oilseed crushing costs have increased since 1975.

*"Cost Components of Farm-Retail Price Spreads". Agricultural Economic Report No. 391. U.S. Department of Agriculture; November, 1977.

TABLE B-13. COOKING AND SALAD OIL: COMPONENTS OF PRICE SPREADS PER 24-OUNCE BOTTLE, 1975

Costs and profit	Farm value 1/	Marketing functions						Retail price
		Assembly and storage 2/	Oilseed crushing	Oil refining	Manufacturing	Wholesaling	Retailing	
				Cents				
Labor	-	-	0.6	0.3	0.5	-	6.5	-
Packaging	-	-	0	0	10.6	-	.6	-
Transportation	-	-	.5	1.1	-	5.0	-	-
Business taxes	-	-	.1	.3	2.0	-	.5	-
Depreciation	-	-	.4	.6	.5	-	.3	-
Rent	-	-	0	0	0	-	1.0	
Repairs	-	-	.2	.1	.1	-	.2	-
Advertising	-	-	3/	3/	2.6	-	1.2	-
Interest	-	-	.5	.2	.2	-	.3	-
Energy	-	-	.5	.3	3/	-	.2	-
Other	-	-	4/ 1.0	4/ 1.7	4/ 2.2	-	2.9	-
Profit before taxes	-	-	- 0.2	2.7	23.2	-	2.3	-
Unallocated	-	1.2	-	-	-	5.6	-	-
Total	35.0	1.2	3.6	7.3	41.9	10.6	16.0	115.6

1/ Imputed from SRS monthly prices received by farmers at country elevator for soybeans, cottonseed, and corn.
2/ Based on the difference between soybean prices, No. 1 yellow, Illinois country shipping points, and farm value.
3/ Less than 0.1 cent.
4/ Includes plant supplies, processing, chemicals, management costs, insurance, legal fees, and selling costs.
Note: Dashes mean not estimated.

Source: "Cost Components of Farm-Retail Price Spreads". Agricultural Economic Report No. 391. U.S. Department of Agriculture; November, 1977.

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Industry Trends and Processing Methods

Soybeans

Soybeans have been a major crop in China, Manchuria, and nearby countries for centuries. Prior to 1940, China and Manchuria provided over 75 percent of the soybeans and soybean products traded on world markets. Following World War II, Chinese exports declined as a result of changing Chinese policies, increasing population, and erratic production. The U.S. soybean industry developed rapidly after the War and by the 1960s, the U.S. had attained a 90 percent share of world soybean trade. In 1980, the U.S. harvested over 67.8 million acres of soybeans (Figure B-8). U.S. production has increased rapidly for a number of reasons including*:

- A reduction in world supplies of fats and oils during World War II
- Inability of the Chinese to supply their traditional European markets with soybeans
- Restrictions on cotton, wheat, and corn plantings in the U.S. opened lands to soybeans
- Worldwide acceptance of soybean meal as a high protein feed for livestock
- Availability of new technology for stabilizing soybean oil.

More recently, Brazil has become a significant producer and exporter of soybeans.

Although soybeans traditionally have been grown in the Orient for food, U.S. farmers in the 1920s and 1930s grew them largely as a substitute for hay. Today, soybeans are processed into oil, meal, and protein products. Soybean oil is used in shortenings, margarines, and salad dressings; defatted cake or meal is an ingredient in livestock feed; and protein products are useful in a variety of human food applications.

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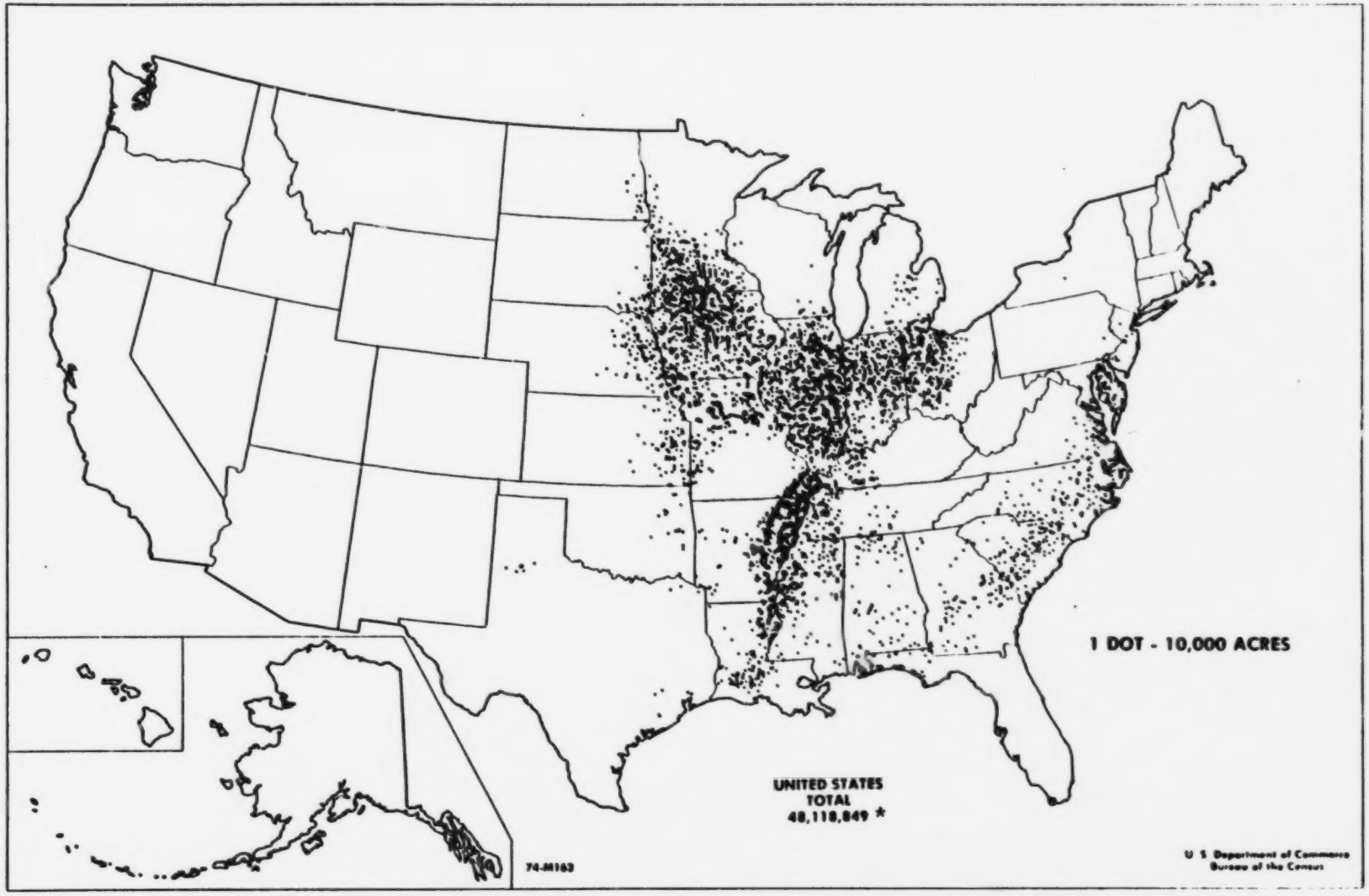
* "Location, Type, and Size of the U.S. Soybean Processing Industry", W. J. Free, as reprinted in World Soybean Research, Lowell D. Hill, editor, University of Illinois at Champaign-Urbana, 1976.



* 1980 soybean acreage harvested = 67,856,000 acres, or 41 percent more than is indicated on this map.

FIGURE B-8. SOYBEANS HARVESTED FOR BEANS, 1974 (ALL FARMS - COUNTY UNIT BASIS)

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Processing and Refining. Soybeans are initially processed by separating oil from the meal. Oil has been extracted by a variety of methods including the use of continuous screw or hydraulic presses. Such presses are rarely used today. Instead a solvent process is preferred. (Pre-press solvent extraction is also practiced.) After the beans are dried and steam conditioned, they are run through cracking, dehulling and flaking apparatus. Oil is removed from the flakes by washing them with hexane. Oil and the solvent are separated by afractional evaporation and the solvent recovered. Although the solvent method is more costly than using presses, more oil is recovered and the higher processing costs are negated. Steam and heat can be used to remove solvent from solvent-wet defatted flakes.

Before the crude soybean oil can be used for edible products, it must be further refined. In the degumming step, phospholipids are removed by hydrating them with water or steam. The phospholipids precipitate out as lecithin which is used in chocolate, margarine, shortening, and frying compounds. Additional steps include the addition of alkalis to neutralize acids and bleaching for pigment removal. Soybean oil can also be hydrogenated which enables it to be used as a substitute for animal-derived fats or other vegetable oils. Soybean oil is typically deodorized to eliminate undesirable flavor and odor components and winterized (chilled) to enable the oil to remain clear at refrigerator temperatures. Reversion is a process for treating the oil so that it will not develop undesirable flavors and odors after storage.*

Although most soybean meal is utilized as a high-protein feed ingredient for livestock and poultry, it can also be processed into three food product groups -- flour and grits, protein concentrates, and protein isolates. Soy flour and grits differ from soy meal in that hulls are removed prior to extraction. Products containing soy flour and grits include baby foods, breads, cereals, and prepared meats. Protein concentrates are prepared from flour to grits, contain at least 70 percent protein, are bland in flavor, and lighter in color and more functional than flour or grits. Soy isolates contain 90 percent protein and are produced to contribute specific functional properties. Products containing isolates include meats, simulated dairy products, and baked goods.**

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* McGraw-Hill Encyclopedia of Food, Agriculture and Nutrition (D.N. Lapedes, editor), 1977, p. 620-621.

** Ibid, p. 621-622.

Industry Trends. Total U.S. soybean processing capacity was estimated to be 1,425 million bushels in 1980, with utilized capacity being 1,040 million bushels (Table B-14). In 1979, average processing capacity per mill was 14.4 million bushels, with average utilized capacity of 11.9 million bushels per mill. Between 1975 and 1980, the ratio of utilized to total capacity has ranged from 66 to 83 percent. The number of soybean mills in the U.S. has declined from a high of 135 in 1967 down to 94 in 1979. However, processing capacity per mill has more than doubled during this period.

The location of U.S. soybean processing plants is indicated in Figure B-9.

Newer processing plants tend to be larger than older plants due to economies of scale. A 1978 study by the University of Arkansas* concluded that capital investment and processing costs did not increa in proportion to volume increases. However, soybean acquisition costs were shown to be highest for the largest plants because of the additional transportation costs. Also, because storage costs were about one-half of the initial investment, it is important to locate new plants near supply areas and existing storage capacity.

Soybean, meal, and oil prices are affected by a variety of factors including**:

- Joint-product aspects of soybean meal and oil
- Multiple market outlets, i.e., domestic and foreign
- Competition from other fats, oils, and livestock feed
- Government programs for soybean oil exports and soybean price supports.
- Existence of organized futures markets for beans, meal, and oil.

Soybeans are the foremost source worldwide for fats, oils, and high protein meal. However, there are many competing sources worldwide and each source contains a different level of oil and protein. Competing

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* Economies of Size in Soybean Processing Plants, 1978, B. J. Mixon and W. R. Morrison, University of Arkansas, October 1979, p. 14.

** Soybeans and Their Products, Markets, Models, and Policy, Houck, Ryan, Subotnik, University of Minnesota Press, 1972, p. 50.

TABLE B-14. ESTIMATED NUMBER OF U.S. SOYBEAN OIL MILLS AND PROCESSING CAPACITY, 1965-80

Year Beginning September	Processing Mills (1)	Annual Processing Capacity				Average Per Mill	
		Total (2)	Utilized (3)	Excess (4)	Ratio of Utilized To Total	Processing Capacity	Capacity Utilized (3)
	Number	Million Bushels			Percent	Million Bushels	
1965	125	600	537	63	89	4.8	4.3
1966	129	650	559	91	85	5.0	4.3
1967	135	750	576	179	77	5.5	4.3
1968	134	750	606	144	81	5.6	4.3
1969	132	800	737	63	92	6.1	3.6
1970	130	875	760	115	87	6.7	3.3
1971	123	900	720	180	80	7.3	5.9
1972	117	925	722	203	78	7.9	6.2
1973	113	1,000	821	179	82	8.8	7.3
1974	108	1,050	701	349	67	9.7	6.5
1975	103	1,100	865	235	79	10.7	8.4
1976	103	1,200	790	410	66	11.7	7.7
1977	99	1,250	927	323	74	12.6	9.4
1978	95	1,300	1,018	282	78	13.7	10.7
1979 (5)	94	1,350	1,123	227	83	14.4	11.9
1980 (6)	NA	1,425	1,040	385	73	NA	NA

(1) Estimate developed by ESS from census data and trade directories. Includes cottonseed and other oilseed mills that process significant quantities of soybeans. (2) Trade estimates. Estimates shown here are approximations of capacity at the beginning of the marketing year. Capacity fluctuates during any year due to new plants coming into operation and additions to existing mills, some mills becoming dormant (due to explosions, fires, strikes, etc.) and dismantling of older mills. (3) Soybeans actually crushed. (4) Difference between total capacity and soybean utilized (crushed). (5) Preliminary. (6) Forecast.

Source: U.S. Department of Agriculture FOS-301, October, 1980.

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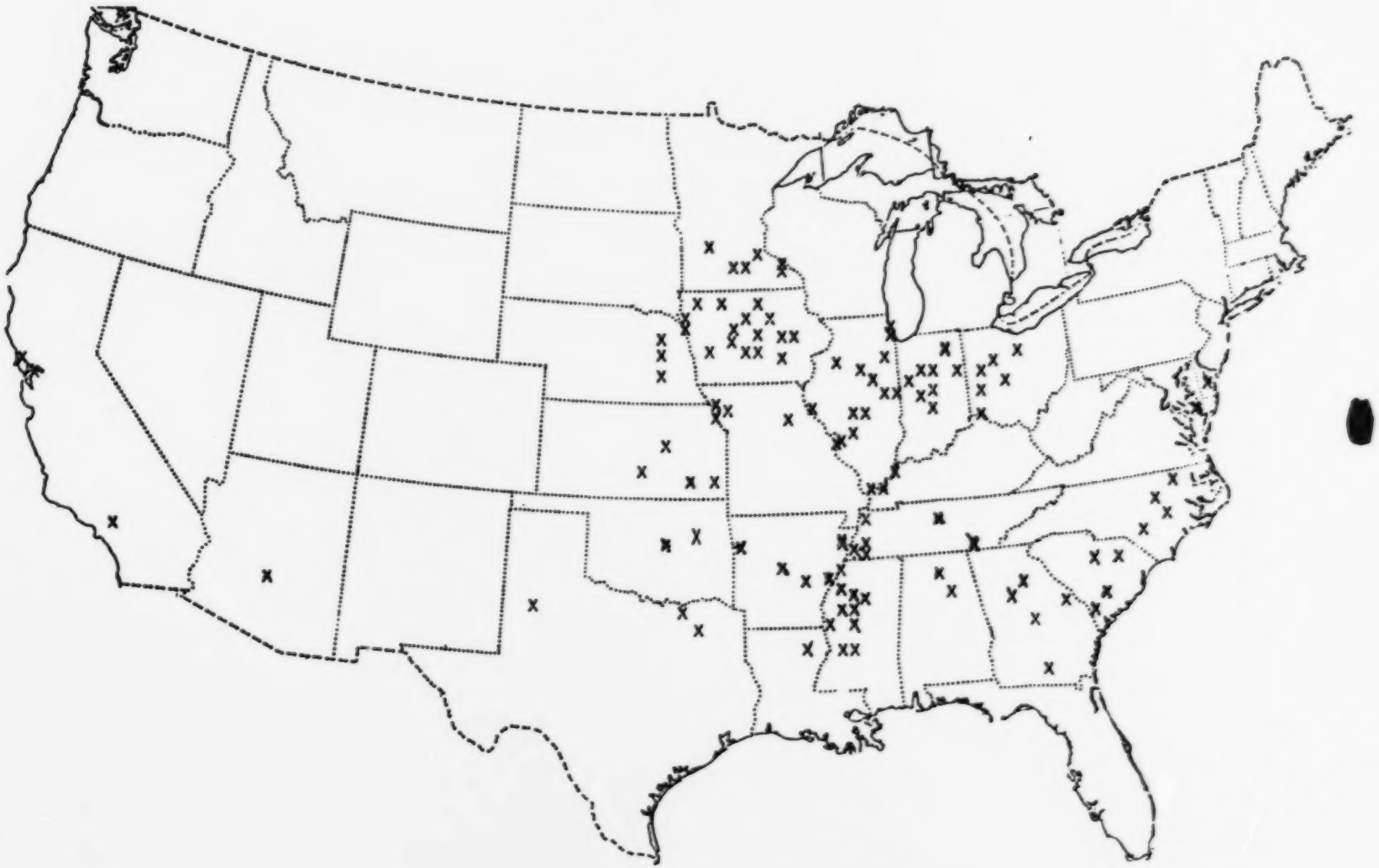

FIGURE B-9. LOCATIONS OF U.S. SOYBEAN PROCESSING PLANTS

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materials include meal and oil from cottonseed, rapeseed, peanuts, sunflowers, and safflowers; oil from tallow, lard, and palm fruit, and meal from fish such as anchovies.

A notable consumer trend is the growing preference for polyunsaturated fatty acids, such as sunflower and safflower oils. Both have a high ratio of polyunsaturated fats and are considered premium oils. These oils are excellent for cooking oils, shortening, and premium grade margarines.

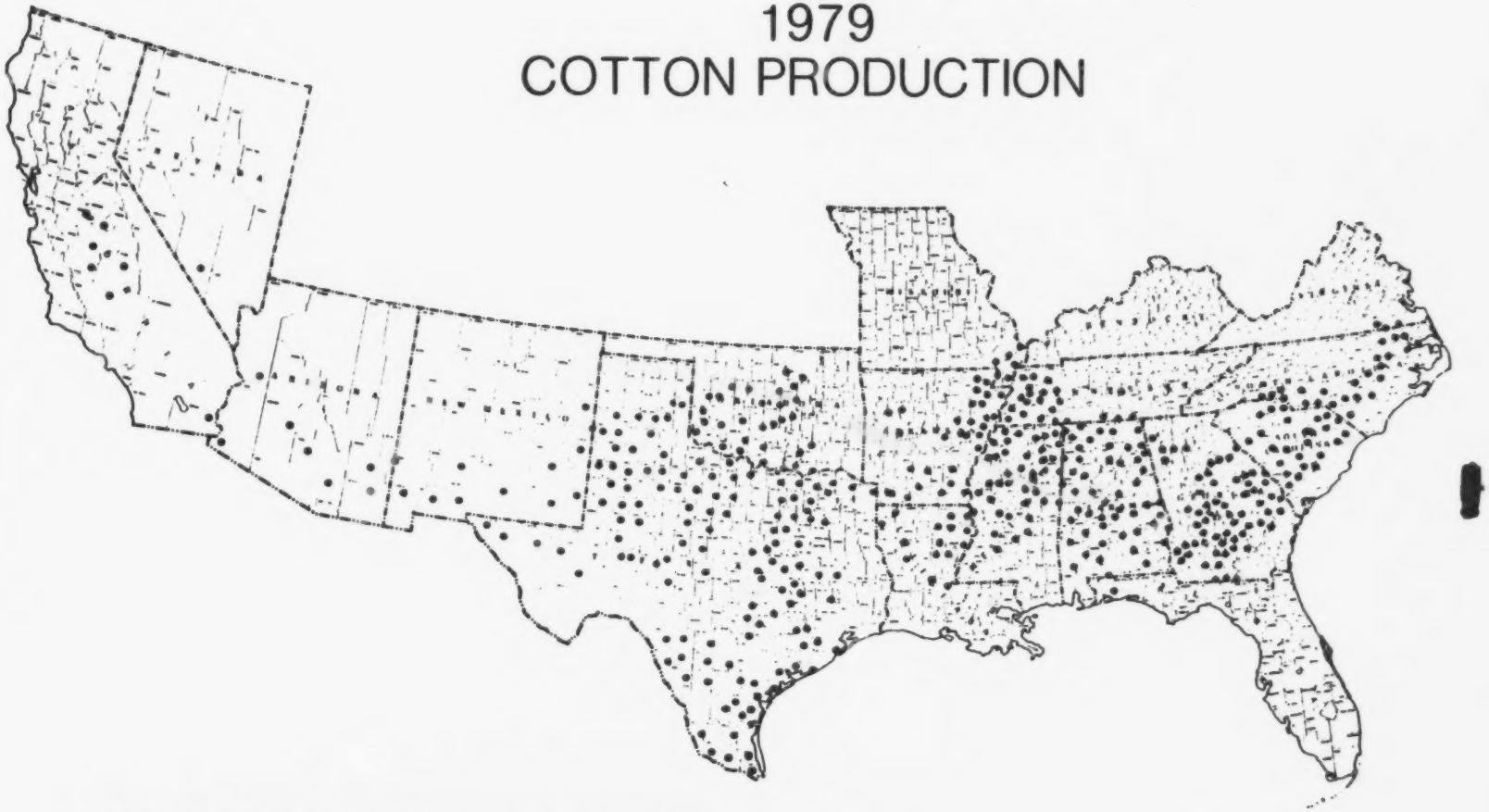
Another notable trend, albeit more slowly accepted by consumers, is the increased use of edible soybean protein products. Applications include the use of soy flour, grits, concentrates, and isolates in a variety of food products.

Cottonseed

Location of U.S. cotton production in 1979 is indicated in Figure B-10.

Although cotton has been used for centuries, the commercial exploitation of cottonseed is of comparatively recent origin. About the time of the Civil War, technology for removing linters and hulls from seed kernels was perfected. This led to the rapid expansion of cottonseed processing activities in the U.S.

The primary products obtained from cottonseed are oil, meal, linters, and hulls. Oil represents about 50 percent of the total value of cottonseed products. Approximately two thirds of cottonseed oil is used in salad or cooking oil, mayonnaise, and salad dressing. Another 25 percent is used in shortening and about 7 percent in margarines. Cottonseed meal accounts for 35 to 40 percent of the total cottonseed products' value and is used primarily as high protein livestock feed in the form of meal, cakes, flakes, or pellets. Cottonseed hulls are also used primarily as livestock feed but valued for their roughage rather than protein contribution. Industrial uses for hulls include usage in plastics, drilling muds, furfural production, rubber manufacture, and petroleum refining. Linter pulp is used in making products such as



o = County in which cotton production takes place.

Source: Cotton, Inc.

FIGURE B-10. 1979 COTTON PRODUCTION BY COUNTIES

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photographic and x-ray film, plastics, smokeless powder, paper, absorbent cotton, gauze, carpet yarns, and sausage casings.*

Processing and Refining. Cotton is harvested mechanically and seed cotton is sent to nearby cotton gins where it is separated into lint and seed. The lint is sold to cotton merchants and the seed is shipped to oil mills for processing. Ginners ship seed quickly since it is subject to rapid deterioration under certain conditions. Cottonseed generally is not transported greater than 100 miles from gin to mill since it is a high bulk commodity relative to value. Cottonseed products have higher value per unit of weight.

In the first processing step, the seeds are cleaned by removing field debris such as leaves, twigs, pieces of bolls, or sand. Then linters (short fibers) are removed and hulls are separated from kernels. Oil is extracted from kernels (also known as meats) by processes similar to those used for soybean oil. However, the screw press is more commonly used for cottonseed pressing accounting for 39 percent of oil production. Solvent extraction is used for 60 percent of cottonseed processing and hydraulic presses for one percent.**

The refining process is also similar to that used for soybean oil. Refining includes the addition of an alkali (sodium hydroxide) to precipitate soapstock and also, bleaching, winterizing, and deodorizing. Cottonseed oil may also be hydrogenated.

Industry Trends. The number of cottonseed crushing mills peaked at about 900 just before World War I. In 1978, less than 90 mills were reported in operation, as noted in Figure 11.*** However, processing capacity has not changed appreciably because the volume of seed processed per mill has increased significantly. The trend to centralized milling operations has occurred due to factors such as transportation improvements, shifts in production areas, economies of scale, and the need for more modern equipment.

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* "Cottonseed and Its Products", National Cottonseed Products Association, Inc., Memphis, Tennessee, 1978, p. 17-24.

** Ibid, p. 17.

*** Ibid, p. 8.

FIGURE B-11. LOCATION OF COTTONSEED PROCESSING PLANTS

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Cottonseed milling is typically a seasonal operation and most mills operate 24 hours a day during the season. Approximately 50 percent of the annual crop is processed during the four months from October to January. From October to March, about 70 percent of the crop is processed.* Many mills also process other oilseeds including peanuts, safflowers, and sunflowers.

Peanuts

Peanuts originated in South America and were transplanted to Spain, Africa, and Asia by Spanish explorers. Later, African slaves brought the peanut to North America. About 1900, production began to expand as equipment became available for planting, harvesting, and processing.

Basically, three types of peanuts are grown in the U.S. -- Virginias (large-kerneled), runners (medium-kerneled), and Spanish (small-kerneled). Some Valencia peanuts which contain three or four small kernels in a long shell are also produced in New Mexico. The location of U.S. peanut acreage is indicated in Figure B-12. There has been little change in location of production since 1974.

In North America, peanuts which contain 26 percent protein are valued as a food source.** In other parts of the world, peanuts are used mostly for oil. About one half of peanuts used in the U.S. are processed into peanut butter. Other important applications are roasted peanuts for snacking, peanut confections, peanut oil, peanut foods such as flour, milk, ice cream, and cheese. Non-food uses for peanuts include wallboard, kitty litter, washing powder, ink, metal polish, soaps and creams, rubber, cosmetics, and medicine.

Processing. After peanuts are dug and allowed to dry in the fields, they are combined and placed into wagons where they are further dried with forced hot air. The peanuts are then sampled and graded by Federal inspectors, purchased, placed into storage, and eventually shelled.

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* Ibid, p. 14.

** "The Peanut Story", National Peanut Council, Washington, D.C., 1980, p. 3.

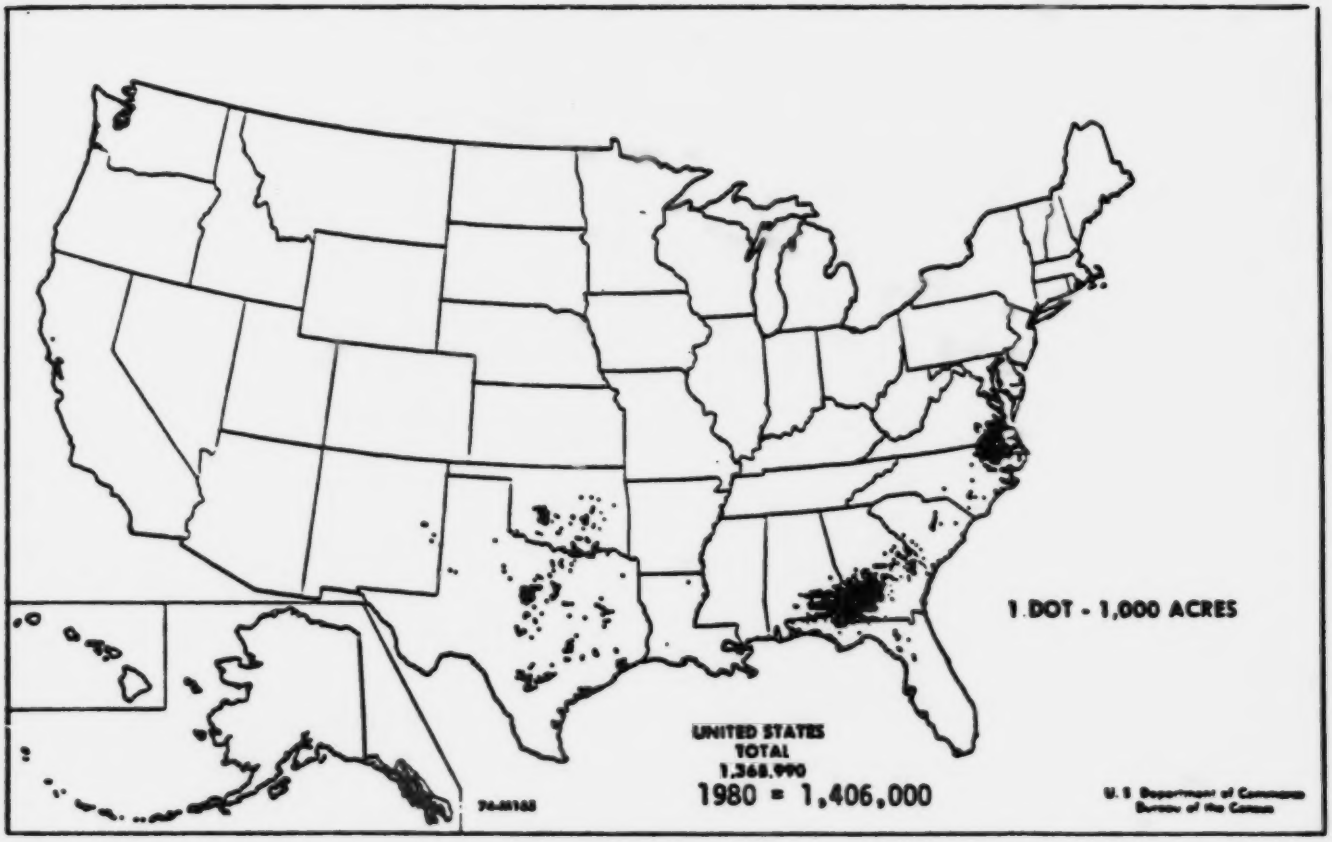

FIGURE B-12. PEANUTS HARVESTED FOR NUTS: 1974
(All Farms - County Unit Basis)

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The shelling process begins with removing dirt and debris and cutting off remaining vines on the shells. Larger pods are separated to be sold as in-shell peanuts (less than 10 percent of the crop) and the remainder are shelled by rubbing them together in drums until the shells open and the kernels fall out.* After more cleaning, the kernels are graded, sized, and bagged.

Peanuts to be used in peanut foods are cleaned again and either wet or dry blanched. Either the seller or a peanut broker typically sells the peanuts to a processor who in turn markets the peanuts to the public in any of several forms.

Peanut oil is produced by applying high pressure to the peanuts. Peanut oil sells at a premium because it is tasteless, can be heated to 450 degrees F** before it smokes, and also does not transfer flavors (which allows it to be used repeatedly for different foods). Peanut oil producer locations are shown in Figure B-13.

Industry Trends. U.S. government controls limit peanut acreage to 1,614,000 acres, grown under approximately 59,000 allotments. However, the U.S. grows about 10 percent of the world's crop on three percent of the world's acreage.*** The U.S. yield per acre roughly tripled between 1950 (900 lbs. per acre) and 1978 and 1979 (2,600 lbs, per acre).

Sunflowers

Globally, sunflowers are important as a source of vegetable oil and other products. However, in the U.S., the sunflower is still considered as a minor crop (see area harvested in Figure B-14). Two types of sunflowers are grown, oilseed and non-oilseed. The oilseed type, which accounts for about 94 percent of total U.S. production, can be processed into vegetable oil and high protein meal. The non-oilseed type is used for human food and bird seed. Hulls can also be separated from the oilseed type, but in the U.S., hulls are seldom removed. Consequently, sunflower meal which is used domestically for feed has a high fiber content.

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* Ibid, p. 9.

** Ibid, p. 13.

*** Ibid, p. 7.

FIGURE B-13. PEANUT (x) AND SUNFLOWER (o) PROCESSING PLANTS

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1980 Area Harvested = 3,482,000 Acres
Oil Varieties

FIGURE B-14. SUNFLOWERS, AREA HARVESTED, 1980

Sunflower oil (or sun oil) is highly valued because it has a favorable ratio of polyunsaturates to saturates*, and is relatively stable. Sun oil is bleachable and has desirable light yellow color and mild flavor characteristics when processed into salad oil. It has achieved a premium price position in some food markets.

Industry Trends. Until the mid 1970s, much of the sunflower oil was grown in the U.S. under contract. This practice is changing as marketing channels develop. The U.S. exports a significant amount of sunflower seed and products. However, much more whole seed is exported than oil. This is due to the European Economic Community practice of taxing imported sun oil, while allowing whole seed to enter EEC countries without duty.

Domestically, northern grown seed is processed primarily in Minneapolis by modified flaxseed processing plants (see Figure B-13). The main output of these operations are margarine and cooking oils with some applications in paints and varnishes. Southern grown sunflower seeds are processed in cottonseed and castor bean processing plants. Oil derived from southern plants is used primarily for deep fat drying by snack food manufacturers, a particularly suitable application because of the higher oleic acid content of southern sunflowers. The lone U.S. plant known to process only sunflower seed is operated by Cargill in Riverside, North Dakota.**

Animal Fats and Oils

Processing. Animal fats are edible or inedible depending on the source of fatty tissue. Approximately 15 percent of animal fats are edible and 85 percent are inedible. Edible tallow is used primarily in shortening.

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* "Sunflower Oil, a Premium Edible Oil", North Dakota Sunflower Council, Bismark, North Dakota.

** Telephone contact with Sunflower Association of America, Fargo, North Dakota.

Lard requires little processing aside from texturization which produces a fine crystal structure and a firm, smooth product. Inedible tallow is used in animal feeds, soaps, fatty acids, lubricants, paints, varnishes, and printing inks. Animal fats are saturated, compared with most vegetable oils. That is, they contain little polyunsaturated and much saturated triglycerides.

Estimated tallow, grease, and animal protein production per head of livestock, and total industry production for the year 1978 are indicated in Table B-15.

The animal raw materials for animal fats and oils are primarily discarded or rejected parts of animals such as fat, skin, meat, bones, and offal. Renderers also process dead animals obtained from farmers, feedlots, and slaughtering plants, as well as restaurant and food store waste such as fat, grease, and bones. Cattle and calves are the major source of tallow, grease, and protein meal (feed) accounting for 63 percent of the tallow/grease and 56 percent of the meal. Hogs contribute only seven percent of the grease and 10 percent of the protein meal production; sheep and lambs, less than one percent of tallow production; poultry, two to three percent of grease and 20 to 35 percent of meal production; dead animals, seven percent of total tallow and grease and 12 percent of protein meal; and restaurant grease, 17 percent of U.S. production of animal fats and oils.*

Raw material and finished product yields for different types of cattle and other livestock are also shown in Table B-15. Yield grades and carcass weights are the most important factors affecting raw material yields for rendering, and thus tallow and protein meal yields from cattle.

Rendering is the process for separating oil and fat from animal tissue. Three basic methods are in current use. In the dry process which is analogous to frying, heat is applied to vessels containing the raw animal material and fat is released as cell proteins coagulate. Wet rendering can be achieved by adding water at low temperatures or under steam pressure at high temperatures. Floating fat is drawn off and either allowed to settle or is centrifuged. Continuous rendering is the newest process and involves chopping and comminuting the fat before heating. Liquid fat is separated by centrifugation.

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* "USDA Study Forecasts Modest Growth in 1980s", as reported by Frank Burnham in Render, December 1980, p. 15.

TABLE B-15. ESTIMATED TALLOW, GREASE AND ANIMAL PROTEIN PRODUCTION, 1978 (BASE PERIOD)

Source	No. of head	Kill floor yields/hd		Fabrication/hd		Estimated production	
		Tallow/grease	Protein	Tallow/grease	Protein	Tallow/grease	Protein
	(000 hd)	lbs/head				mil. lbs.	
Beef							
Steers	18,650	64.5	34.0	62.1	37.2	2,348	1,321
Heifers	11,747	55.7	29.4	52.6	31.5	1,272	715
Cows	8,464	47.5	47.5	19.8	44.0	570	774
Bulls	791	60.7	34.2	29.3	65.0	71	78
Calves	4,170	3.23	8.25	10.9	7.4	59	65
Subtotal	43,722					4,320	2,953
Hogs							
Barrows and gilts	75,527	--	--	6.12[1]	6.66	462	503
Sows	4,020	--	--	10.6[1]	11.52	43	46
Stags and boars	773	--	--	8.9[1]	9.68	7	7
Subtotal	80,315					512	556
Sheep and Lambs							
Sheep and lambs	5,369			6.0	4.25	32	23
Poultry	3,479,100	.37 lbs per head[2], 15 % grease, 85% meal				193	1,094
Hide and Trim Fleshings	43,722	(15 lb per head of raw material)		3.91[3]	3.20[3]	171	140
Dead Stock	--	--	--	--	--	448	603
Outdated Consumer Cuts	--	--	--	--	--	24	24
Total						5,700	5,393
Restaurant Grease	estimated on bases of 6 lb/capit x 90% of population (218.5 million)					1,180	--
Grand Total						6,880	5,393
Census (M 20 K Reports)							
Inedible						5,520	NA
Edible tallow						835	NA
Total						6,355	4,970

1/ Does not include lard.
2/ Includes feather meal.
3/ Based upon an average yield of 47.4 percent with 55 percent tallow and 45 percent protein.

Source: United States Production, Consumption, Trade, and Stocks of Tallow/Grease, Lard, and Animal Protein Meals -- Estimates and Projections, by Development Planning and Research Associates, Inc. (Manhattan, Kansas) and Schmittker Associates, Inc. (Washington, D.C.) for U.S. Department of Agriculture, April 1980.

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Industry Trends. The DPRA/Schnittker Associates study completed for the U.S. Department of Agriculture in April, 1980* indicated that during the 1970s, production of tallow, grease and protein meal exhibited considerable variability, largely reflecting changes in slaughter levels and the cattle cycle. It also revealed that restaurant grease and rendered poultry products will be steady growth areas in terms of tallow, grease and meal production.

Animal feed is the major growth market for inedible tallow and grease that potentially could be substituted for diesel fuel. Fats added to animal feeds increased at an annual rate of nearly four percent during the 1970s. The use of fat in high efficiency broiler rations and the general expansion in broiler production has accounted for most of the growth over this period. Although the use of fats in soap manufacture declined during the 1950-60s, in the 1970s the long-term trend slowed and reversed as rising petroleum costs associated with making synthetic detergents encouraged greater use of fats in soap manufacturing. U.S. fatty acid production, as an end use of inedible tallow and grease, has also been an important growth area during periods of economic expansion.

Industry trends are toward increased concentration among packers, increased use of boxed beef, and a decrease in the amount of fat trimmed from retail cuts. The changes suggest a long-term decline in the amount of production by independent renderers. However, in the late 1970s, the independents' share of processing of both tallow/grease and protein meal increased. A gradual shift of production to packer-renderers is expected.

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* United States Production, Consumption, Trade, and Stocks of Tallow/Grease, Lard and Animal Protein Meals -- Estimates and Projections, U.S. Department of Agriculture, Foreign Agricultural Service, April 1980.

APPENDIX C

PRODUCTION POTENTIAL FOR SELECTED OILSEED CROPS

APPENDIX C

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APPENDIX C

PRODUCTION POTENTIAL FOR SELECTED OILSEED CROPS

The potential yield of a crop is the result of a number of biological, chemical, and physical interactions. Many of these factors can be manipulated to a given extent, e.g., soil fertility, irrigation, etc., whereas others cannot, e.g., photosynthetic pathway. Considerations of productivity must include:

- Level of crop development (amount of genetic manipulation and size of the genetic base);
- Climatic, edaphic (soil-related) and hydrologic factors:
- Carbon fixation pathway (C_3, C_4, or CAM)*;
- Partitioning patterns (when/where the reduced photosynthetic carbon is translocated);
- End-product composition (carbohydrate, protein, or oil);
- Length of crop growth cycle (annual, biennial, or perennial); and,
- Level of agricultural management (utilization of fertilizers, irrigation, pesticides, etc.).

Furthermore, it must be recognized that potential productivity may not be positively correlated with either maximum economic return (per land area or unit input) or efficiency of non-renewable resource utilization.

Table C-1 highlights the average and estimated potential commercial yields of selected oilseeds. The numbers presented as potential commercial yields were based on conversations with experts in breeding and agronomy of the selected oilseeds, analyses of potential yields under experimental conditions, and a knowledge of crop improvement considerations. They are not meant to reflect absolute values but rather to present a relative index. In addition, the confidence limits associated with the potential yields of commercial oilseeds, e.g., corn, coybean, and cotton, are much narrower than those of the newer, underexploited oilseeds.

Several generalizations may be made concerning the potential commercial yields of the selected oilseeds. First, oil yield is the

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* C_3 (Calvin-cycle), i.e., sunflower, soybean, wheat, and barley.
  C_4 (Hatch-Slack pathway), i.e., corn, sorghum, and sugarcane.
  CAM (Crassulacean acid metabolism), i.e., pineapple, Opuntia (cactus), and agave.

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prime concern, plants which have been selected for other products, e.g., carbohydrate, protein, or multiple products, are at a distinct disadvantage. However, a reorientation of selection criteria may resolve this problem. Second, the level of agricultural management (intensity of production inputs) most greatly affects potential productivity. Third, climatic, edaphic, and hydrologic factors are important, but may be modified by management. Fourth, the perennial plant type may be advantageous over an annual because an effective canopy (foliar display) is present for a greater part of the growing season (which allows photosynthesis to occur for a longer period). Fifth, when comparing oilseeds, photosynthetic pathway and end-product composition have a limited impact on productivity.

The data indicate that there is tremendous room for biological improvement in commerical oilseed yields. The question which exists is whether the economic incentive is strong enough to elicit further exploitation.

TABLE C-1. AVERAGE (U.S.) AND POTENTIAL COMMERCIAL YIELD OF SELECTED OILSEEDS

Oilseed Species	Seed Yield (lb/acre)		Oil Yield (lb per acre/gal per acre)				Growth Conditions
			U.S. Average		Potential		
	U.S. Average	Potential	Lb.	Gal.	Lb.	Gal.	
Castorbean (Ricinus communis)	848	3,400	382	48	1,342	170	Irrigated
Chinese Tallow Tree (Sapium sebiferum)	--	10,000*	--	--	1,537	200*	Dryland
Cotton (Gossypium hirsutum)	791	1,700	127	16	306	40	Irrigated
Crambe (Crambe abyssinica)	1,000	2,100	350	45	735	100	Irrigated
Corn (High Oil) (Zea Mays)	--	5,300	--	--	532	70	Dryland
Flax (Linum usitatissimum)	709	1,600	253	33	676	90	Dryland
Peanut (Arachis hypogaea)	2,122	4,600	673	87	1,458	190	Dryland
Safflower (Carthamus tinctorius)	1,495	2,200	493	64	792	100	Dryland
Soybean (Glycine max)	1,767	3,000	316	41	527	70	Dryland
Sunflower (Helianthus annuus)	1,182	2,200	473	61	880	110	Dryland
Winter Rape (Brassica napus)	--	2,400	--	--	958	130	Dryland

*Estimated by Potts (1946) and Bolley and McCormack (1950) but requires further testing. Along with the oil, 1,485 pounds of tallow would be produced. These estimated yields would occur 3-5 years after propagation and it has been hypothesized that the yields do not decline for 25 to 30 years.

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OPPORTUNITIES FOR EXPANDING VEGETABLE OIL PRODUCTION

Cropping System Opportunities

The availability of oilseeds as substitutes for middle distillate fuel is dependent upon the amount of land in oilseed production and the crop yields associated with that land. From an agricultural systems perspective, opportunities affect both rotation cropping and sequential cropping. Rotation cropping is defined as the repetitive cultivation of an ordered succession of crops (or crops and fallow) on the same land with one cycle requiring several years to complete. Sequential cropping differs from rotation cropping in that it involves growing two or more crops in sequence on the same field during one year. For example, the production of corn during one growing season followed by a soybean crop the next season, followed by winter wheat the following season, constitutes rotation cropping, whereas sequential cropping would be illustrated by the production of winter wheat and a soybean crop in one year.

Changes in rotation cropping and sequential cropping systems will occur over the next few decades and it will be possible to modify systems to accommodate oilseed production for substitution of middle distillate fuel. The key will be to develop optimal systems of a regional scale based on sound practices and fundamentals of crop production, resource conservation, and economics.

Considerations of the impact of integrating oilseed production into rotation cropping and sequential cropping will be highlighted in the following sections. The differences may appear subtle to researchers and policy makers with non-agricultural backgrounds; however, these potential impacts may greatly affect the day-to-day operations within the agricultural sector.

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Rotation Cropping

Among the promising rotation cropping systems which may evolve over the next two decades is a combination of corn and sunflower. This combination could replace much of the acreage that is currently utilized for the corn and soybean rotation in the Corn Belt and the Lake States. This change, if implemented, would potentially increase oil production from a given acre by about 50 percent based on the current oil yields of soybean (41 gal/acre) and sunflower (61 gal/acre). However, the corn/sunflower rotation system would yield a correspondingly smaller quantity of protein.

In the development of any new rotation cropping system, considerations must be given to economic and environmental issues as well as biological developments. Cautions must be taken to ensure adequate income to the farmer while maintaining the integrity of the soil and water resource base. Losses of prime farmland due to the erosion, salinity, and other causes must be held to a minimum.

Sequential Cropping

Changes in sequential cropping patterns should provide additional means for increasing oilseed production from current cropland. On a large scale, the most promising sequential cropping pattern is the double cropping* of oilseeds following production of winter small grains. Examples include:

- Sunflower following wheat in the Northern Plains
- Soybean following wheat/barley in the Southeast and Southern Corn Belt
- Winter rape following cotton/corn/sorghum in the Southeast and Southern Plains
- Peanut following wheat/rye in the Southeast.

*Double cropping is defined as growing two crops in the same field during the same year, in sequence.

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In addition, the sequential cropping of safflower following winter vegetables in the Mountain and Pacific regions might increase oil production.

The economics of double cropping wheat and soybeans in Ohio is shown in Table C-2. Although soybean yields are reduced due to the shorter growing season, a soybean yield of 20 bushels per acre should be possible in an "average" year, at least in the southern half of the state. Double cropping wheat and soybeans would allow the grower an estimated return over variable costs of $158 per acre, compared to $95 per acre for growing only wheat, assuming a wheat yield of 45 bushels per acre. When land and other fixed costs are included, the return for double-cropping wheat and soybeans is $9 per acre, compared to an estimated loss of $28 per acre for wheat alone.

TABLE C-2. COMPARISON OF 1980 OHIO CROP BUDGETS FOR WHEAT AND DOUBLE-CROPPED WHEAT-SOYBEANS

		Wheat-Soybeans (Grain Only)			Wheat (Grain Only)		
Yield/Acre	(bu)	30&20	45&20	60&20	30	45	60
Receipts	($)	260	320	380	120	180	240
Variable costs	($)	146	162	184	74	85	101
Fixed costs	($)	116	149	182	90	123	156
Total costs	($)	262	311	366	164	208	257
Return above variable costs	($)	114	158	196	46	95	139
Return above total costs	($)	-2	9	14	-44	-28	-17
Variable cost per bushel	($)	-	-	-	2.47	1.89	1.68
Total cost per bushel	($)	-	-	-	5.47	4.62	4.28

Source: Ohio Crop Enterprise Budgets, 1980 (Grains, Forages). Departments of Agricultural Economics and Rural Sociology, and Agronomy, The Ohio State University.

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Along with the conventional sequential cropping patterns, a number of new systems might develop. In the United States, about 105 million acres of wet soils are used for crop production. A third of this acreage is inadequately drained. Potentially, a new crop such as the perennial Chinese tallow tree might make use of part of the southern wetlands. Furthermore, systems may evolve in some of these wetlands in which annual oilseeds are intercropped* with the Chinese tallow tree. This mix would allow for higher oil production and a shorter period for realizing a return on investment.

The required farm management skills are much greater under sequential cropping systems than under rotation cropping systems. Water availability is critical under the sequential cropping systems. Also, the sequential cropping systems demand timely and careful management, including early harvest, use of short-season cultivars, narrow rows for double-cropped oilseeds, selection of herbicides based on planting methods and crop sequence, and consideration of no-tillage planting of the summer oilseed crops.

Even with proper management, sequential cropping entails greater risks which often are beyond the control of the grower. For example, soybeans planted in Ohio in early-to-mid-July following wheat harvest are subject to potential yield and quality reduction from early frosts which could occur in mid-September, even though the normal date of the first killing frost is mid-October.

Potential Production of Vegetable Oils on Pasture, Range and Forest Land

It is important to generate some concept of the potential production of vegetable oils relative to United States' requirements for

*Intercropping is defined as growing two or more crops simultaneously on the same field.

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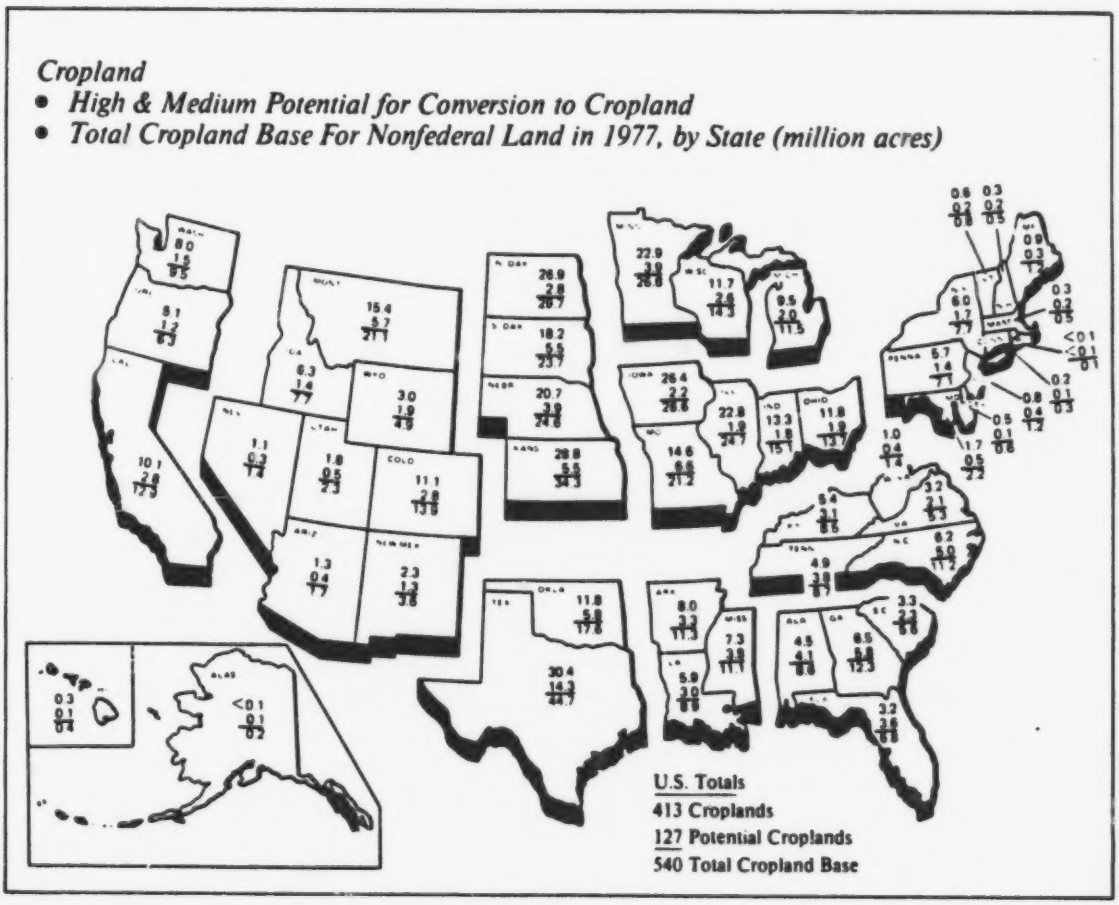
diesel and other middle distillate fuel. This report presents some preliminary data which indicate the location and quantity of land required to produce one billion gallons of vegetable oil that potentially could be substituted for diesel fuel. One billion gallons of diesel fuel represents about 35 percent of total diesel fuel utilized in producing U.S. crops in 1978. The one billion gallons could be used as a potential stockpile upon which to draw in the event of a curtailment in U.S. oil imports, mitigating serious impairment of U.S. crop and livestock production in the event of a national emergency precipitated by reduced supplies of liquid fuels.

A recent National Agricultural Land Study, in which several government agencies participated,* provided information on land available for agriculture in the nation's ten farm production regions and the 50 states. About 127 million acres of land currently not cropped were indicated as having a "high or medium potential" for use as cropland. Most of this acreage now is forested, or in pasture or range. According to the 1977 survey, 36 million of the 127 million acres have a high potential for conversion to cropland, while 91 million acres have medium potential. A "high potential" rating required favorable cropland characteristics (e.g., adequate moisture supply, soil temperature, water permeability, slope, etc.) and also evidence of similar land being converted to cropland during the last 3 years. A "medium potential" rating required favorable characteristics, but conversion costs generally are expected to be higher than those for soils with a "high potential" rating.

Figure C-1 indicates the existing croplands, and the land area designated as having a high or medium potential for conversion to cropland, by state, for the year 1977. It is important to note that the estimate of land potentially convertible to cropland is changing constantly as some of the potential acreage is converted to non-agricultural uses. For example, it has been estimated that the United States loses three million acres of prime farmland to sub-divisions, highways, reservoirs,

*National Agricultural Lands Study, Interim Report #5, America's Land Base in 1977; Robert Gray, Executive Director, New Executive Office Building, 722 Jackson Place, N.W., Washington, D.C., December, 1980.


Cropland
• High & Medium Potential for Conversion to Cropland
• Total Cropland Base For Nonfederal Land in 1977, by State (million acres)
U.S. Totals
413 Croplands
127 Potential Croplands
540 Total Cropland Base

Source: National Agricultural Lands Study.

FIGURE C-1. CROPLAND AND POTENTIAL ACREAGE FOR CONVERSION TO CROPLAND, BY STATE, 1977

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and other urban uses each year. On the other hand, rising profits in farming will result in expansion of the acreage qualifying as having high and/or medium potential for use as cropland.

Table C-3 utilizes data from the previous studies on potential cropland to calculate the hypothetical production of vegetable oils as potential substitutes for diesel fuel. It was assumed that the currently produced oilseed crops such as sunflower, soybeans, and peanuts, would be the most likely source of vegetable oils in the relatively near term, i.e., over the next five years. These oilseed crops primarily are produced in the seven farm production regions noted in the left hand column of Table C-3. The Pacific, Mountain, and Northeast farm production regions are not included because they either (1) do not have large quantities of land potentially convertible to cropland, or (2) do not produce significant quantities of soybeans, sunflowers, or peanuts. However, these lands certainly could be available to produce these crops, if necessary, in addition to other oilseeds such as winter rape, safflower, Chinese tallow, etc.

It was assumed that 20 percent of the total potential land (101 million acres) convertible to cropland could be utilized to produce oilseeds. Sunflowers were assumed to be the primary oilseed crop in the Northern Plains, Southern Plains, and Lake States. Soybeans were assumed to be the primary oilseed crop in the Corn Belt, Delta States, and Appalachian Region. Peanuts were assumed to be produced in the Southeast region. Under the assumption of 20 percent of potentially convertible cropland being converted to these oilseeds, it would result in slightly over 20 million acres being converted to oilseeds in the seven production regions.

The assumed oil yields per acre were based on the average oilseed yields of the specified crop within each farm production region. For example, even though soybeans can be grown in both the Corn Belt and Delta States, soybean yields in the Delta States are generally about 75 to 80 percent of yields in the Corn Belt. The "medium estimate" of oil

TABLE C-3. HYPOTHETICAL PRODUCTION OF VEGETABLE OILS AS DIESEL FUEL SUBSTITUTES, UTILIZING POTENTIAL CROPLAND IN SEVEN FARM PRODUCTION REGIONS*

Farm Production Region	Area with High and Medium Potential For Conversion to Cropland, 1977** (Million Acres)	Primary Oilseed Crop	Assume 20 Percent of Potential New Cropland Converted to Primary Oilseed Crop (Million Acres)	Assumed Oil Yield (Gallons/Acre)			Total Oil Production (Million Gallons)		
				Low (Less than Average)	Medium (Current Average)	High (Long Term)	Low	Medium	High
Northern Plains	17.7	Sunflower	3.54	46	61	76	163	216	269
Southern Plains	20.1	Sunflower	4.02	33	44	55	133	177	221
Lake States	8.5	Sunflower	1.70	46	61	76	78	104	129
Corn Belt	14.4	Soybeans	2.88	31	41	51	89	118	147
Delta States	10.1	Soybeans	2.02	24	32	40	48	65	81
Southeast	15.8	Peanuts	3.16	65	87	109	205	275	344
Appalachian	14.4	Soybeans	2.88	26	34	43	75	98	124
Total	101.0		20.20	39	52	65	791	1053	1315

*Does not include potential contribution of oilseed plants that could be double-cropped or intercropped with other crops.

**Includes pasture, rangeland, forests and other lands including farmsteads, windbreaks, etc.; from U.S. Department of Agriculture, National Agricultural Lands Study.

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yields per acre is based on existing average oilseed yields. The assumed "low yield" is 25 percent less than the current average while the "high yield" is 25 percent greater than the current average. It should be noted that the "high yield" estimates are still considerably less than the potential yields noted previously in Table C-1 on page C-3.

Under the assumptions noted above, total potential vegetable oil production in the seven production regions under the "medium oil yields" would be 1.05 billion gallons. The highest volume of vegetable oil would come from peanut production in the Southeast (275 million gallons) and sunflower oil in the Northern Plains (216 million gallons).

The 9.26 million acres of cropland assumed to be converted into sunflowers compares with average 1978-1980 sunflower harvested areas of 3.7 million areas. The 3.6 million acres of potential peanut land compares with current area harvested of about 1.5 million acres. (As previously indicated in this report, U.S. government acreage allotments limit peanut acreage to slightly over 1.6 million acres. Therefore, a change in the allotment system would be necessary if additional peanuts were to be grown). The 7.7 million additional acres of soybeans is a relatively small fraction of the harvested area of 67 million acres.

It is important to note that these figures are not projections of what should or is likely to occur, in terms of producing vegetable oils as potential diesel fuels substitutes. Rather, they are intended to provide some perspective on the potential contribution of existing commercialized oilseed crops in terms of land requirements relative to potential land availability. Important considerations that remain to be addressed are the availability of sufficiently large contiguous land areas, (as opposed to many scattered small plots of potential cropland), marketability of by-products associated with increased oilseed production, energy balances, as well as the overall desirability of using the potential croplands for producing fuel as opposed to some other use. It also is important to note that other potentially higher yielding oil crops such as Chinese tallow have a potential, if commercialized, to reduce the land

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requirements. Over the long term, i.e., over the next two decades, higher yielding crops such as Chinese tallow may offer the best alternative for increased vegetable oil production, given the limited availability of cropland.

The Food Versus Fuel Question

Since the early 1970's, when the United States' energy problems were brought to the forefront, the issue of utilizing agricultural resources for food or fuels has been debated. Strictly speaking, it is not so much a matter of utilizing the agricultural resources per se for fuel, as it is a question of using finite supplies of land and water to produce fuel. When petroleum prices were relatively low, i.e., prior to the 1973 OPEC oil embargo, agricultural products were far too high priced to be considered as energy feedstocks. However, as energy and petrochemical prices have risen, agricultural commodities have become attractive alternative energy and chemical feedstocks, adding pressure on food supplies and prices. The competition for land and water resources presents critical choices to policy makers to intervene in free markets, either to hasten or delay the point at which the energy-food interface is joined. The choices for each country are weighted by the relative scarcity of fuel sources, especially petroleum, and domestic production (Rask, 1980).*

Up through 1980, it appeared that domestic energy supply problems would be more severe than food shortages during the 1980's. Over the long run, energy markets may experience greater increased demand and an earlier supply plateau than is anticipated for food markets. If this result occurs, there would be an eventual joining of the energy-food interface in competitive markets with or without policy interference. It has become apparent from the findings of this survey that price elasticity issues may be of paramount importance.

*Rask, N., "Agricultural Resources for Food or Fuel: Policy Intervention or Market Choice", Mershon Quarterly Report, The Ohio State University, Volume 5, Number 2, Winter, 1980.

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Rask (1980) indicates some positive and negative effects for the United States for enacting policies on the side of energy, as opposed to food. The positive effects include:

(1) In the long run, more stable supply of liquid fuels, particularly important from a national security perspective

(2) An improved balance of payments situation

(3) A short-run bridge to the use of shale oil and coal liquefaction and a smoother transition to "more probable" energy future (i.e., increased use of renewable resources)

(4) Increased income and employment in rural areas

(5) Substitutions for present "surplus food production" programs (i.e., transfer of present subsidies for income maintenance, set-aside acres, support prices, etc. to provide incentives for crop production).

Rask's negative effects for intervening on the side of energy are:

(1) Higher energy and food prices, at least in the short run

(2) A smaller "food reserve" for the world in times of food production shortfalls

(3) A reduction in food exports, thus lower foreign exchange earnings.

The effect of decontrolled oil prices presumably will be to stimulate energy conservation and the use of renewable resources. Following this reasoning, production of oilseed crops as diesel fuel extenders will be stimulated by the rising oil prices.

Cropland, Technology, and the Use of Vegetable Oils as Emergency Diesel Fuels

The National Agricultural Lands study emphasized that there is no free land bank from which to withdraw croplands to replace those

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being lost to other uses. New croplands are available only at various costs to other segments of the national economy. These costs may include red meat production, dairy products, wood products, the expense of converting from current use of cropland, and significant changes in environmental and wildlife values. Land conversion from a dwindling land base should be made in full recognition of these tradeoffs and in concert with them (National Agriculture Land Study, 1980).

Crosson (1979)* discusses the effect of technological change upon the demand and supply of cropland. Improvements in technology (e.g., improved plant cultivars, control of diseases and pests, etc.), lower production costs per unit of output, and consequently prices, stimulating demand for crops and the land to produce them. Technological improvements may be land-saving, land-using, or neutral. Land-saving technologies that reduce the amount of land required relative to other inputs, result in a reduced rate of increased demand for land than if the improvements are land-using or neutral. Significant land-saving improvements may offset the effect of higher crop demand, resulting in a net decline in the amount of land and crops even though crop production is higher. For example, the use of minimum tillage systems reduces erosion and permits the cropping of land unsuitable for conventional row crop systems. Another more recent technology, not yet fully commercialized, involves breaking the lignocellulosic complex in wood and cereal straws so that lignin, cellulose, and hemicellulose can be obtained separately. This technology reportedly results in a roughage substitute with improved digestibility and feed efficiency for cattle*. Such a technology has the potential to reduce the land required for conventional forages (i.e., hay) now fed to cattle. Thus, land formally devoted to hay production might be transferred into production of oilseed crops to produce vegetable oils.

*P. Crosson, "Agricultural Land Use: A Technological and Energy Perspective", in Farmland, Food, and Future; Soil Conservation Society of America, 1979.

In summary, even though the United States has a fixed quantity of land for food and fuel production, technological advances, economics, and environmental considerations will dictate whether or not new crop lands will be developed to produce vegetable oils as potential replacements for diesel fuels.

*Pro-Cel Nutritional Report, A Stake Technology Processed Product; W. J. Esdale, Stake Technology, Ltd., Nepean, Ottawa, Canada, August, 1979.

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ECONOMICS OF VEGETABLE OIL RECOVERY

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APPENDIX D

ECONOMICS OF VEGETABLE OIL RECOVERY

The cost of recovering vegetable oils for use as diesel fuel is a function of the size of the facility and choice of recovery technology. The costs per gallon would generally be expected to decline as the capacity of the equipment used increases primarily because the costs of labor and equipment per gallon throughput would be less. However, many farmers have significant spare time when not planting and harvesting their crops. In addition, most farmers have become skilled in equipment repair, welding, electrical work, and other skills required to construct an oil recovery facility. The accounting for the use of the farmer's time is quite different from the accounting for employing skilled labor to perform the same tasks. Therefore, it was judged appropriate to consider the economics involved in vegetable oil processing at several scales of operation including the following:

- A small on-farm unit to serve the needs of fewer than five farmers
- A local cooperative to serve about 60 farmers
- A regional unit to serve about 2000 farmers.

Sizing Considerations

For large commercial operations, different types of equipment are used for recovery of vegetable oils from various oilseeds. In very large plants, such as those used to process 1,000 to 3,000 tons of oilseed per day, solvent extraction is normally used to reduce the oil in the cake to nearly negligible levels. If the oilseed contains greater than about 20 percent oil, the seed is normally prepressed mechanically to achieve a level similar to that of soybeans first. However, for smaller commercial plants up to about 100 to 200 tons per day, use of mechanical oil expellers is reasonably competitive to direct solvent extraction or prepressing followed by solvent extraction. It should be noted that there are

significant economies of scale for commercial operations up to about 2,000 to 3,000 tons per day. Accordingly, very few plants are now being built in the United States in the 50 to 500 ton-per-day size range.

As indicated previously, the specific operations used for processing different oilseeds will vary, particularly in the seed preparation steps prior to pressing or extracting the oil from the seed. Thus, capital and operating costs do vary from one oilseed to another. For this preliminary study, two oilseeds were selected for further economic study. Based on data estimating the U.S. average and potential seed yield per acre and the gallons of oil that could be recovered per acre, it was observed that peanut and sunflower oilseeds would represent two varieties with reasonable oil recovery potentials and crops that could be grown in many parts of the country. Therefore, these seeds were selected for further study.

The smallest available mechanical oil expellers are capable of handling about 50 to 100 pounds of oilseeds per hour. According to the manufacturer of one of these units (Simon-Rosedowns, Ltd.), sunflower seeds that have not been dehulled or heat-conditioned can be pressed to 14 percent residual oil in the cake. According to tests conducted at the University of Idaho and North Dakota State University using such small units, systems can be designed that would require a minimum of attention during operation. Thus, it has been assumed for the on-farm unit that the unit could be in operation about 26 weeks a year, 6 days a week, and 14 hours a day, or 2,184 hours a year, if operated by an aggressive farmer. As indicated by Table D-1, if the farmers were to operate at the equivalent of full capacity 90 percent of the 2,184 hours per year using sunflower seed as feedstock, then good yields (above the current average yield of about 1,200 pounds per acre) and somewhat poor yields (about 1000 pounds per acre) from about 120 to 170 acres of sunflowers would produce sufficient oil to farm about 900 to 1,250 acres. Similarly, a farmer using whole peanut kernels from about 70 to 90 acres (depending on whether relatively higher or lower yields than the current average yield of about 2,100 pounds an acre are obtained) would produce enough fuel to farm about 1,150 to 1,600 acres. Thus, if it were assumed that the typical farmer interested in use of vegetable oil for diesel fuel farmed about 500 acres, then one farmer could plant about 20-30 percent of his acreage to sunflowers

TABLE D-1. IMPACT OF VARIOUS SCALES OF OPERATION ON SUNFLOWER AND PEANUT PROCESSING

	On-Farm Unit	Cooperative Unit	Commercial Unit
Hourly capacity, pounds/hour			
Undecorticated	88.2	458	-
Decorticated	-	-	16,667
Annual hours of operation	2,184	7,920	7,920
Operating rate, percent[a]	90	90	90
Annual filtered oil production, gallons			
Sunflower	6,670[b]	147,400[b]	7,306,000[c]
Peanut	8,510[b]	179,600[b]	10,070,000[c]
Acres required to provide seed to recovery plant			
Sunflower at:			
1,500 pounds/acre	116	2,176	102,200
1,000 pounds/acre	174	3,264	153,300
Peanut at:			
2,500 pounds/acre	69	1,306	59,400
2,000 pounds/acre	88	1,632	74,260
Acres farmed with oil from plant[d]			
Sunflower			
5 gallons diesel/acre[e,f]	1,270	28,080	1,392,000
7 gallons diesel/acre	907	20,060	993,900
Peanut			
5 gallons diesel/acre	1,620	34,220	1,917,000
7 gallons diesel/acre	1,157	24,440	1,370,000

(a) An operating rate of 90 percent indicates that the average throughput over the annual hours of operation is 90 percent of the hourly capacity.

(b) Assumes 2 percent oil loss during filtration step.

(c) Assumes negligible oil loss during filtration step.

(d) For purpose of discussion, use of neat vegetable oil is assumed in making these estimates. Current technology would require conversion to the methyl ester and/or blending with at least 50 percent diesel fuel to achieve the viscosity needed for use in unmodified engines.

(e) Five or seven gallons diesel use indicates that current use of diesel fuel is currently 5 or 7 gallons.

(f) Studies reported by North Dakota State University indicate that about 5 percent more vegetable oil than diesel by volume would be required for sunflower oil. It has been assumed that peanut oil would have the same characteristic.

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and produce sufficient oil to serve the needs of about two farmers. Meanwhile, a peanut farmer could plant about 15 percent of his acreage to peanuts and produce sufficient fuel for about two to three farmers.

Capacity selection for a cooperative-type venture was somewhat more difficult because of the many capacity options available. However, it was decided to use a machine with a capacity of 5.5 short tons per day (458 pounds an hour) operated at an efficiency of 90 percent for 330 days per year. The machine selected will produce a residual oil content in the meal cake of about 7 percent if the seed is conditioned by heat and if the oilseeds are not dehulled. Although the hourly capacity of the unit is only about 5 times as large as the on-farm unit, annual production from the unit would be 21 times as large as the on-farm unit because of round-the-clock operation. Thus, based on analysis of Table D-1, if about 20 farmers each planted 100 acres of sunflowers, then sufficient fuel would be provided for about 50 farmers with 500 acres each. Similarly, if about 10 farmers each planted 100 acres of peanuts, sufficient fuel would be provided for about 60 farmers with 500 acres. Although larger machines could be envisioned, this small machine would appear to be capable of producing fuel for a reasonably sized cooperative venture.

As indicated previously, a cooperative plant sized to crush about 200 tons per day of oilseed would not be competitive with conventional large-scale operators with 2,000 to 3,000 tons per day plants serving current vegetable oil markets. However, the economics of a plant sized to crush 200 short tons per day distributing both the meal and vegetable oil to farmers located in a region would not be quite as unfavorable.

A commercial scale plant could be supported by about 750 to 1000 farmers if each planted about 100 acres of sunflowers and had good yields. Sufficient oil could be produced in this plant to provide the fuel needs for about 2,700 to 3,800 farmers, again each with 500-acre farms. Viewed another way, if the planting density of sunflowers producing 1,500 pounds per acre was 8.8 percent over 1,812 square miles (42.6 miles by-42.6 miles) of fully arable land, then the agricultural diesel fuel needs for the area would be matched, assuming the equivalent of 6 gallons of No. 2 diesel fuel were used per acre. The sunflower seed produced would also provide the seed for the 200

ton-per-day plant. Thus, the 200 ton-per-day commercial unit would seem to represent an ambitious regional program.

Process Details

Work on winter rape seed at the University of Idaho and on sunflower seed at North Dakota State University indicates that relatively simple systems can be used to obtain a filtered but crude vegetable oil which may be suitable for use as diesel oil replacement. The steps involved are seed cleaning, tramp iron removal, feed rate control, expelling the oil, disposal of the by-product meal as animal feed, oil settling, filtration of the settled oil, and storage. Although preheating the seed to about 220 to 240 F might be desirable to obtain higher yields, this has not yet been clearly demonstrated. As indicated previously, dehulling is not necessary. However, peanuts should be destoned to protect the expeller.

Further processing such as degumming, dewaxing, alakli refining, and/or conversion to esters may eventually prove to be necessary for proper long-term engine operability and durability. However, this has not been proven to date in preliminary tests. Operation of diesel engines using peanut oil has apparently been more troublesome than operation with sunflower oil due to coking on the injectors, but the specific processing required to overcome this problem is not clear. The orientation in estimating the capital and operating costs for this study will generally be optimistic; that is, the estimated costs will be minimized to make such ventures as attractive as practical. Therefore, as new information is developed that implies additional processing is required, the costs can be expected to increase. Conversely, mass production savings on expellers have not been estimated, if a substantial market develops.

On-Farm Unit

A block diagram of the process proposed for sunflower seed in an on-farm unit is presented as Figure D-1. The peanut process flowsheet would be the same except the peanuts would be destoned prior to the expeller. If

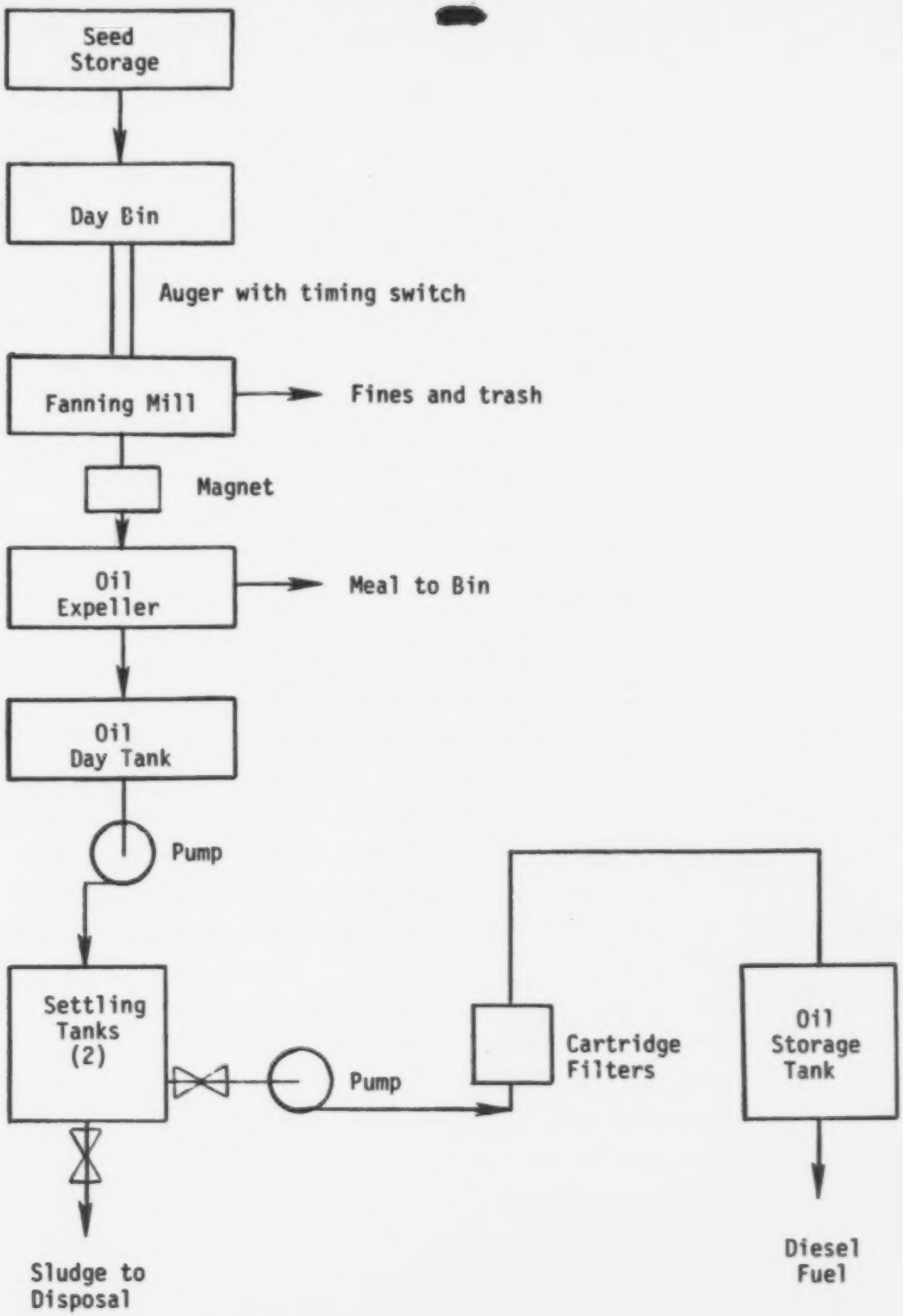

FIGURE D-1. BLOCK DIAGRAM OF ON-FARM UNIT FOR SUNFLOWER PROCESSING

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the processing building is located adjacent to the seed storage bin, then a day bin would not be required. A fanning mill is a small seed cleaner. Although elevators now perform most of the seed cleaning function, it is believed that many farms may have old, but functional, units on hand from operations performed 25 to 40 years ago. According to individuals at North Dakota State and Idaho University, the feed rate to the small expellers might be controlled by one of two ways: high and low level micro switches on the small hopper on the expeller providing an on-off operation to an auger forwarding cleaned seed to the expeller, or a timing switch on the auger forwarding seed to the fanning mill. To avoid serious damage to the expeller, a magnet should be used to remove any tramp iron in the seed.

Flakes of meal cake containing about 14 percent oil are discharged from the expeller. Protein content is about 25 percent. Because of the high oil content, this meal should be used as animal feed as soon as practical before it becomes rancid or autoxidizes. It will have to be mixed with other feeds to dilute the residual oil in cattle feed rations. This high-oil product may be a fire hazard unless it is stored and handled properly.

Oil is expelled from the sides of the screw press and collected in a small day tank from which it is pumped to one of two settling tanks. After the oil has been allowed to settle 3 to 10 days (depending on the ambient temperature), the clarified oil is filtered through 3 micron cartridge filters. The sludge settled to the bottom of the settling tank is pumped to drums for disposal. The quantity of sludge anticipated is about 2 percent of total sunflower oil production, according to North Dakota State University investigators. The quantity of sludge might be reduced if it were continuously recycled to the expeller. Upon standing, some polymerization of the vegetable oils would be anticipated, which would significantly increase the viscosity of the oil. Thus, it would be proposed to refilter the oil shortly before use as diesel fuel.

Cooperative Unit

Although the cooperative unit has only about 5 times the hourly capacity of the on-farm unit, there are two important changes in the basic flow

sheet from that shown for the on-farm unit. These are that the seed will be cooked at about 220 F prior to introduction to the expeller and a plate and frame filter press will be used for crude oil filtration. See Figure D-2 for a block diagram of the proposed facility. The peanut process flow sheet would be the same, except that a stoner would be used to remove any stones from the peanuts.

Cooking of the oilseeds shortly before introduction to the oil expeller is consistent with commercial practice. The main impacts are that recovery of oil from the seeds will be significantly improved and the residual oil in the meal cake will be reduced to 7 percent, which will result in a higher quality animal feed product. The use of the plate and frame filter press was simply a design consideration to reduce capital and operating costs. Simon-Rosedowns does not recommend dehulling at capacities of less than about 10 tons per day because of economic considerations.

Commercial Unit

The 200 ton-per-day commercial plant has equipment that is properly sized to perform all of the functions that the on-farm and cooperative equipment performs plus several other features. An isometric drawing depicting much of the equipment to be used is presented as Figure D-3. All of the equipment presented on the drawing is to be used in the proposed plant except that only two expeller presses (instead of three) and only one stacked cooker will be used (instead of three), and no cake cooler fitted with an exhaust fan and cyclone, pellet mill, or bagger will be included. However, a stoner, cracking mill, seed screens, (partial) dehuller, and oil winterization unit will be added to the equipment list for the process plant. In addition, a boiler system will be required along with adequate storage bins and tanks for oilseed, meal cake, and winterized oil. Winterization after a 30-day holding period was suggested as an alternative to final filtration. The same equipment was proposed for both peanut and sunflower processing.

Anderson International suggested that instead of operating the expellers on broken, cooked sunflower meats mixed with hulls, it may be more economical to consider feeding uncrushed but cleaned whole kernels to the

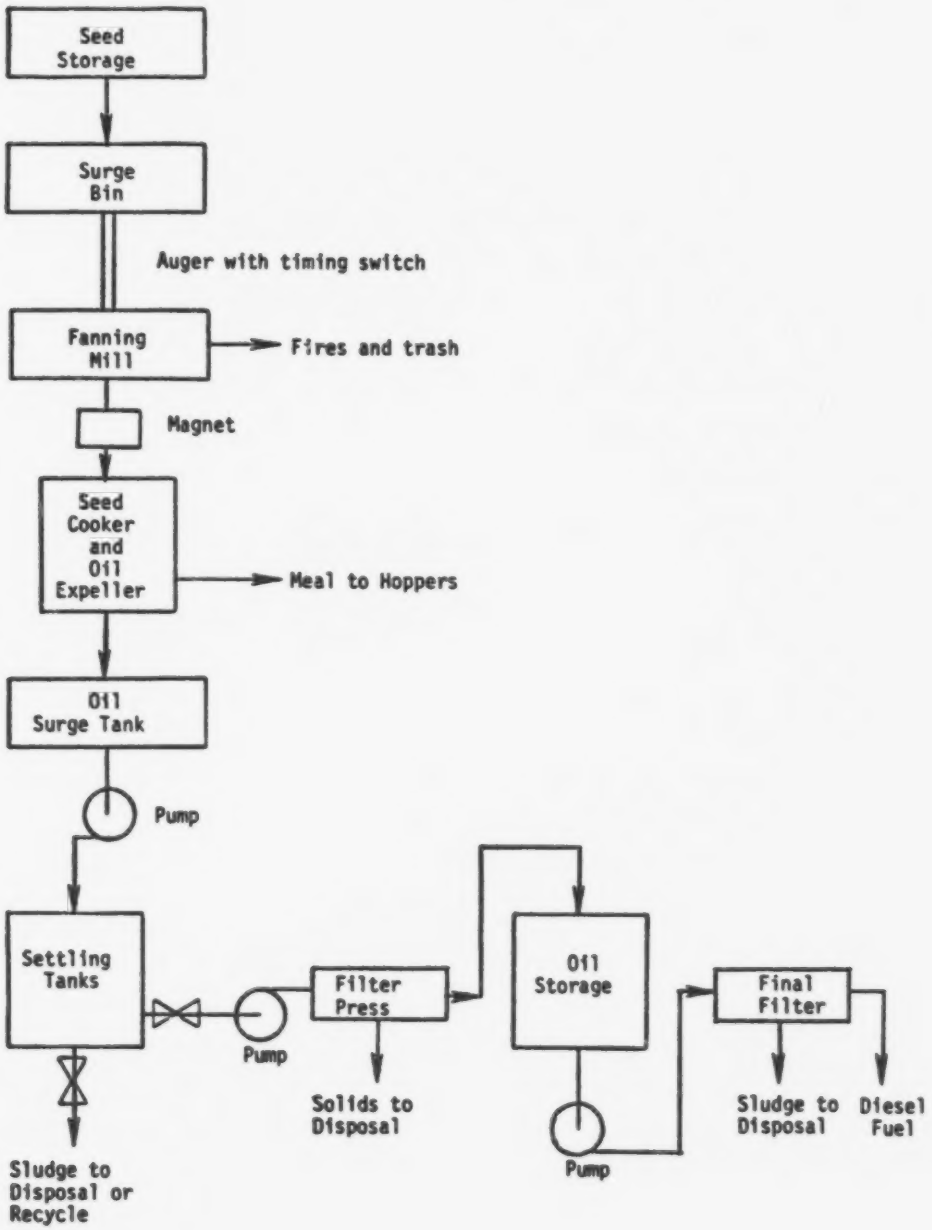

FIGURE D-2. BLOCK DIAGRAM OF COOPERATIVE UNIT FOR SUNFLOWER PROCESSING

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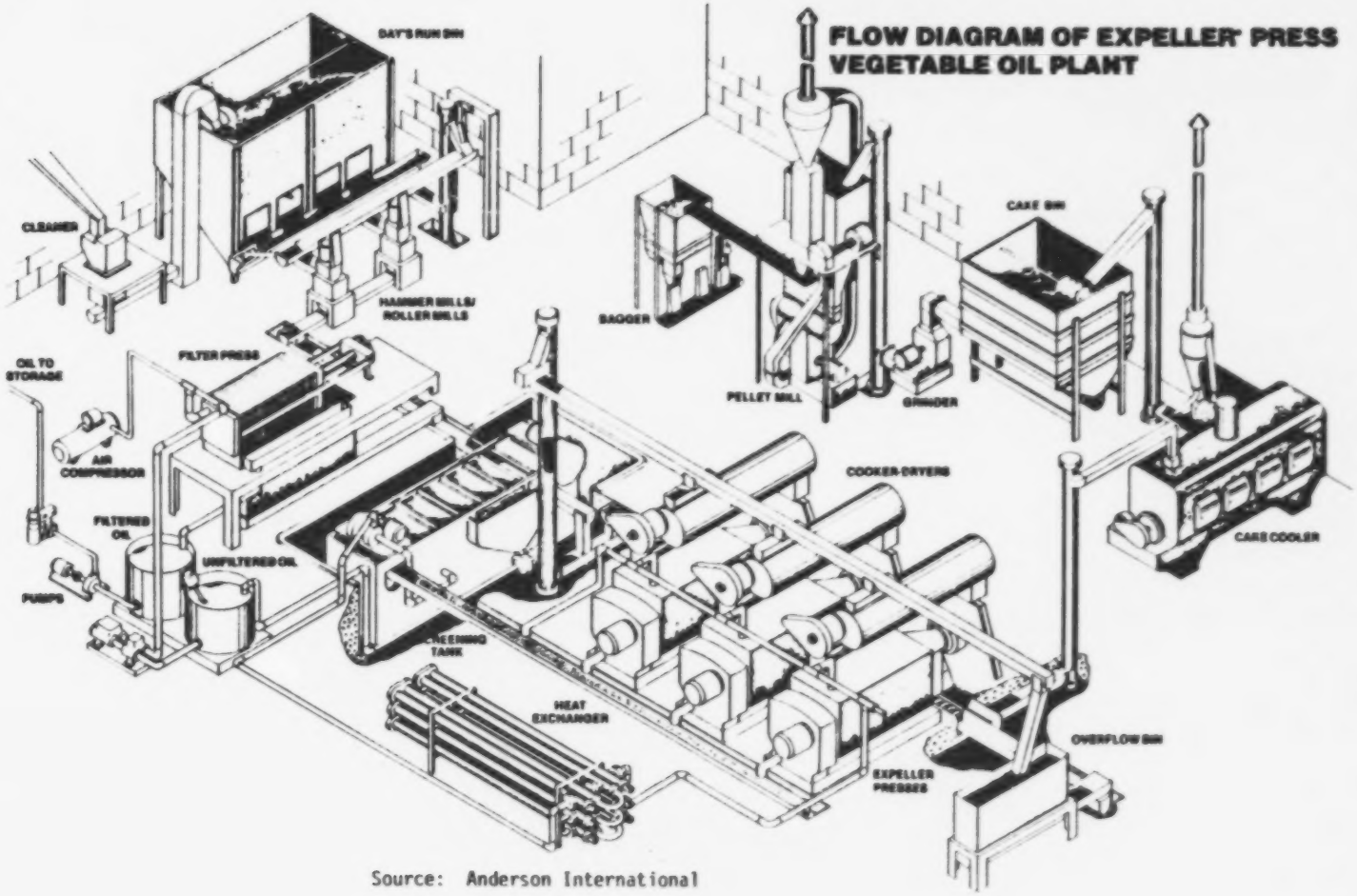

Source: Anderson International

FIGURE D-3. FLOW DIAGRAM OF A COMMERCIAL UNIT FOR SUNFLOWER OR PEANUT PROCESSING

expellers without cooking-drying. A portion of the seed preparation equipment would be avoided as would the stacked cooker-dryer and boiler system. In addition, operating costs for boiler fuels would be avoided while some modest power reduction could be realized. However, residual oil in the sunflower would double to nearly 11 percent and the quality of the meal cake would be reduced.

Capital and Operating Costs

An optimistic basis was selected because the vegetable oil is to be used to solve an emergency situation. Further processing such as degumming, winterizing, dewaxing, alkali refining or conversion to esters may be required to produce an acceptable diesel fuel alternative. Installation and operating costs have assumed a very low wage rate for the farmers involved in the on-farm and cooperative ventures. This is on the basis that much of the operating labor for the on-farm unit could be provided by children or wives. Also, the wage rate of the farmers involved would not be high because he cannot regularly expect to find alternative employment when not actively involved in farming. Finally, an effort has been made to view interest and return on investment for the on-farm and cooperative ventures as a farmer might in an emergency situation. The reader can use this format with other assumptions and observe the impact on the overall economics.

On-Farm Unit

The capital investment for the on-farm unit is presented in Table D-2 for both a sunflower and a peanut processing operation. In some cases, the required equipment is assumed to be on hand such as the main storage bin for seed and an auger and/or truck to move the seed from storage to a small day bin. In other cases, such as the fanning mill and settling and storage tanks, a compromise is taken between purchase of new tanks and use of a mill or tanks that are on hand or can be purchased in used condition. Thus, total capital investment might vary by up to about $8,500 more or less than the values presented. Installation cost is based on the direct labor being provided by

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TABLE D-2. CAPITAL INVESTMENT FOR ON-FARM UNIT

Basis

Hourly feed rate: 88.2 pounds undehulled seeds per hour
Operation : 2,184 hours per year (156 days per year, 14 hours per day)
Efficiency : 90 percent

Sunflower seeds required: 86.7 tons/year
Filtered oil produced : 6,670 gallons/year
Meal cake produced (14 percent oil) : 60.5 tons/year
Sludge produced : 136 gallons/year

Peanut seeds required: 86.7 tons/year
Filtered oil produced: 8,510 gallons/year
Meal cake produced (14 percent oil) : 53.4 tons/year
Sludge produced : 174 gallons/year

Equipment Items	Cost, Dollars Sunflower	Peanut
Main seed storage bin - on hand	$ 0	$ 0
Auger or truck to move seed to day bin - on hand	0	0
Day bin - about 64 cubic feet required - say plywood	75	75
Auger to fanning mill - on hand or new, say	250	250
Fanning mill - 600 pounds per hour, new unit $2,500 Assume used unit $500 - say	1,500	1,500
Stoner - $3,000 new (for peanuts only)	-	3,000
Expeller - Simon-Rosedowns Mini Press	7,600	7,600
Meal day bin - about 32 cubic feet required - say plywood	50	50
Oil day tank - 50 to 65 gallons, say on hand or use a drum	25	25
Settling tanks - 2 each, 600 gallons each. $4,000 new One on hand or used - say	4,000	4,000
Cartridge filter and pump stand (portable)	1,250	1,250
Final oil storage tank - 3 months inventory. About 4,000 gallons, $7,000 new or on hand - say	3,500	3,500
Miscellaneous pipe, electrical, concrete and other materials	500	500
Installation labor and start-up, 560 hours at $6/man-hour	3,360	3,360
Buildings. Use existing building	0	0
TOTAL	$22,360	$25,360

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the farmer at $6 per hour rather than skilled labor at $14.48 per man-hour. It was also assumed that the farmer could relinquish use of about 500 square feet of space in a building suitable for the equipment if a concrete slab and foundation were poured.

Total capital investments are estimated to be about $22,500 and $25,000 for sunflower and peanut processing, respectively. No working capital is included in the estimate. These costs exclude any charges for engineering, equipment procurement, and construction supervision and overhead, which are presumed to be provided by the farmer. In addition, some time would probably be provided by the farmer to straighten out problems which would occur when the unit was first placed in operation.

Annual operating costs for conversion, excluding seed costs and by-product meal credits, are presented in Table D-3. The 4 hours-per-day operating labor charge assumes that the unit can be started in the morning after about one hour during which the day bin for seed would be filled. Pumping out the oil day tank and disposing of the meal cake would require about another 45 minutes before supper. Every tenth day about 600 gallons of oil from the settling tanks would have to be filtered sometime over the succeeding 10 days. This activity could probably be handled as an incidental task during the previously mentioned activities. A total elapsed filtration time of about 12 hours would be required. Prior to final use, the oil should probably be "final" filtered. The flow rate during this filtration is expected to be somewhat slower and the operation could be left unattended except for start-up and shut-off of the pump. Occasionally, the sludge from the settling tanks must be pumped out to drums and discarded along with the filter cartridges. However, this will not be a frequent activity. Thus, about 2 hours per day of active work, combined with say twelve 10-minute spot checks through the day by the hired help, children, or wife, would constitute the required labor. The $5 hourly rate may appear to be unusually low. However, it should be remembered that much of the time to be allocated to the venture will be during times when other farming activities are at a low ebb and alternative employment cannot be found. Except for the capital charges and tax considerations, most of the items in the table are relatively self-explanatory.

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TABLE D-3. ANNUAL OPERATING COSTS FOR ON-FARM UNIT

Basis: See Table D-2

Expense Item	Annual Cost, Dollars Sunflower	Peanut
Utilities Power - 10,050 kw-hr at $0.07/kw-hr 12,215 kw-hr	$ 704	$ 855
Filter cartridges - one per 75 gallons at $15 each	1,334	1,702
Labor - 4 hours per operating day at $5/hr	3,120	3,120
Supervision - assumed voluntary	0	0
Maintenance materials - 2.5 percent of original capital cost of new equipment	771	847
Overhead - assumed voluntary	0	0
Insurance and property tax - 3 percent per year of original capital investment	926	1,016
Capital charge - over 10-year period at 15 percent interest (payment of both principal and interest on borrowed capital)	4,455	5,053
TOTAL, excluding tax considerations	$11,310	$12,593
Less income tax credits and deductions: Investment tax credit: 20 percent at end of first year levelized over 10 years at 15 percent discount rate		
Sunflowers: $4,472 in first year only	(775)	-
Peanuts : $5,072 in first year only	-	(879)
Tax deduction for depreciation: 5-year straight line levelized over 10 years at 15 percent discount rate times effective rate of 40 percent		
Sunflowers: $4,472 depreciation first 5 years	(1,195)	-
Peanuts : $5,072 depreciation first 5 years	-	(1,355)
Tax deduction for interest: Declining interest payments over 10 years levelized over 10 years at 15 percent discount rate times the effective tax rate of 40 percent		
Sunflowers: $3,354 interest first year, 581 tenth year	(1,019)	-
Peanuts : $3,084 interest first year, 659 tenth year	-	(1,156)
TOTAL, including tax considerations	$8,321	$9,203

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The capital charge is based on the assumption that a 10-year loan at 15 percent interest would be acquired for the entire amount of the capital expenditure. Note that there is no equity position, nor is there any return on investment (profit) or income taxes on profit. In a sense, the annual operating costs are calculated at breakeven with no profit. The incentive for making the investment is to avoid the risk of not being able to plant or harvest because of the lack of diesel fuel. Thus, a proper profitability study would be based on the total farming activity of the farmer of which the oil expelling operation would probably constitute a small segment.

The farmer would be able to take some deductions and tax credits which would represent savings on income tax. These are an investment tax credit of 20 percent in the first year and deductions for (declining) interest payments over 10 years and equipment depreciation over the first 5 years. These have been levelized over the entire 10-year life envisioned for the facilities by use of a 15 percent discount factor. The income tax credit represents a direct reduction from the taxes to be paid by the farmer. However, depreciation and interest represent deductions from gross income to obtain net income upon which the marginal effective tax rate (tax bracket) is paid. It has been assumed that the marginal tax rate for the typical farmer would be about 40 percent.

Based on Tables D-2 and D-3, a farmer processing 86.7 tons per year of sunflower seeds and producing 6,670 gallons per year of oil (6,352 gallons of diesel oil equivalent) and 60.5 tons per year of meal cake would suffer conversion costs of $8,321 per year. This is $1.31 per gallon of diesel oil equivalent, prior to addition of the net cost of the sunflower seed. Net oilseed cost is defined as the raw material cost after allowance has been made for the sale of the by-product oilseed protein cost. For example, when sunflower seed sells for $200 per ton and by-product meal sells for $130 per ton, the net oilseed cost is about $1.16 per gallon. Then, the total oil cost would be almost $2.50 per gallon. If the farmer chose to value his incremental sunflower seed at $130 per ton, the net oilseed cost would be $0.50 and the diesel fuel substitute would cost $1.80 per gallon. A farmer processing 86.7 tons per year of peanuts producing 8,510 gallons per year of oil (assumed to be equivalent to 8,105 gallons of diesel oil) and 53.4 tons per year of

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meal cake would have annual conversion costs of $9,203, which is $1.135 per gallon of diesel fuel equivalent prior to addition of the net peanut cost.

Cooperative Unit

The capital investment for the cooperative unit is presented in Table D-4 for both sunflower and peanut processing. About the same costing procedure was applied to the cooperative unit as was applied to the on-farm unit except that, in general, new equipment was purchased; the fanning mill was the only exception.

Although it is anticipated that about 3,000 to 4,000 gallons per year (9 to 11 gallons per day) of "waste" oil sludge would be generated from the oil settling tanks, it is believed that all this sludge could be recycled through the oil expeller if the expeller were properly equipped with an injection port. Such recycle of vegetable oil settlings is common commercial practice. Thus, it is likely that yield can be increased by 2 percent above that shown, and a troublesome waste problem can be avoided. However, this aspect needs confirmation.

Materials for a new building were included in the estimate, which was assumed to be self-installed. In general, most equipment items were assumed to be self-installed by the farmers except the main oil storage tank and boiler, which were assumed to be installed by contractors.

Annual operating costs for conversion excluding seed costs and by-product meal costs credits are presented in Table D-5. It is reasonably certain that the unit should have a fulltime operator. In addition, the operation of the plant will require significant paperwork.

The calculations dealing with tax considerations were performed in the same manner as those for the on-farm unit. In effect, the cooperative has been formed as a partnership and pays no income taxes because it has no profits.

Based on Tables D-4 and D-5, the plant would process 1632.3 tons per year of seeds and yield 147,436 gallons per year of sunflower oil (equivalent to 140,415 of diesel fuel) and 1,053 tons per year of meal cake at a conversion cost of $200,665 or $1.43 per gallon diesel fuel equivalent prior to

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TABLE D-4. CAPITAL INVESTMENT FOR COOPERATIVE UNIT

Basis

Hourly feed rate: 458 pounds undehulled seeds per hour
Operation : 7,920 hours per year (330 days per year, 24 hours per day)
Efficiency : 90 percent

Sunflower seeds required: 1,632.3 tons/year
Filtered oil produced : 147,436 gallons/year
Meal cake produced (7 percent oil) : 1,053 tons/year
Sludge produced : 3,009 gallons/year

Peanut seeds required: 1,632.3 tons/year
Filtered oil produced: 179,640 gallons/year
Meal cake produced (7 percent oil) : 930.2 tons/year
Sludge produced : 3,667 gallons/year

Equipment Items	Cost, Dollars Sunflower	Peanut
Main seed storage bin - 5 day inventory, 2,500 bushel at $5/bushel	$ 12,500	12,500
Augers to seed surge bin	1,000	1,000
Surge bin - 12 hour inventory 250 bushel at $6/bushel	1,500	1,500
Auger to fanning mill, new	350	350
Magnet	750	750
Fanning mill - 600 pounds per hour, new unit $2,500. Assumed used unit $500, say	1,500	1,500
Stoner - $3,000 new (for peanuts only)	-	3,000
Seed cooker and oil expeller - Simon-Rosedowns Maxoil system	54,000	54,000
Meal discharge hopper and auger system	1,000	1,000
Meal storage hoppers, 2-1/2 days inventory, 2 each, 250 bushel at $6/bushel	3,000	3,000
Oil surge tank - 55 gallon drum (used)	25	25
Settling tanks - 4 each, 10-day inventory total, 1,600 gallon each, $6,400 each	25,600	25,600
Plate and frame filter press CeCoCo filter press type B with pump	8,300	8,300
Oil storage tank, 3 months inventory, 50,000 gallons	28,000	28,000
Plate and frame filter press (final filter)	8,300	8,300

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TABLE D-4. (CONTINUED)

Equipment Items	Cost, Dollars Sunflower	Peanut
Final filtered oil storage tank, 8 days inventory, 5,000 gallons	$ 14,300	14,300
Fuel dispensing system pump	1,500	1,500
Recycle sludge oil pump to expeller	1,400	1,400
Building 750 sq ft at $15/sq ft	11,250	11,250
Oil or gas boiler, softener, blowdown system and feed system	19,600	19,600
Miscellaneous pipe, electrical, concrete and other materials	4,000	4,000
Purchased labor and overheads to install field-erected storage tank and boiler	39,700	39,700
Other installation labor by farmers, 3,400 hours at $6 per hour	20,400	20,400
TOTAL	$258,875	$261,875

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TABLE D-5. ANNUAL OPERATING COSTS FOR COOPERATIVE UNIT

Basis: See Table D-4

Expense Item	Annual Cost, Dollars Sunflower	Peanut
Utilities		
Power - 207,500 kw-hr at $0.06/kw-hr	$ 12,450	$ -
209,700 kw-hr	-	12,580
Fuel oil - 5,620 gallons at $1.20/gallon	6,740	6,740
Filter supplies	4,000	4,000
Direct labor - 7,920 hours per year at 14.30 per hour including fringes	113,260	113,260
Day foreman, clerk, supervisor 1,920 hours/year at $15.75 per hour including fringes	30,240	30,240
Maintenance materials at 2.5 percent of original capital cost of new equipment and buildings	6,500	6,570
Overhead - generally voluntary except for accountant	2,000	2,000
Insurance and property tax - 3 percent capital investment	7,800	7,890
Capital charge - payment of both principal and interest at 15 percent on borrowed capital over 10 years	51,580	52,180
TOTAL, excluding tax considerations	$234,570	$235,460
Less income tax credits and deductions[a]		
Investment tax credit levelized over 10 years on equipment at 15 percent discount rate		
Sunflowers: $49,525 in first year	(8,580)	-
Peanuts : $50,125 in first year	-	(8,685)
Depreciation: 5-year straight line on equipment and 15 years[b] on buildings levelized over 10 years at 15 percent discount rate times effective tax rate of 40 percent		
Sunflowers: $50,275 first 5 years	(13,530)	-
Peanuts : $50,875 first 5 years	-	(13,690)
Interest: Declining interest payments over 10 years at 15 percent discount rate times the effective tax rate of 40 percent		
Sunflowers: $38,831 first year and $6,728 in tenth year	(11,795)	-
Peanuts : $39,281 first year and $6,806 in tenth year	-	(11,930)
TOTAL, including tax considerations	$200,665	$201,150

(a) See Table D-3 for more details for the basis of these items.

(b) Final five years of depreciation on buildings not included.

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addition of the net oilseed cost of perhaps $0.50 to $1.15 per gallon of vegetable oil. If peanuts were processed, then 179,640 gallons per year of peanut oil (171,086 gallons diesel fuel equivalent) and 930.2 tons per year of meal cake would be produced at an annual conversion cost of $201,150. The conversion cost would be $1.76 per gallon diesel fuel equivalent. The potential for increasing the oil yield by 2 percent by recycle of the oil sludge in the tank bottoms to the expeller is judged to be good, but the values indicated above do not include this potential.

Commercial Unit

The capital investment for the small 200 ton-per-day commercial unit is presented in Table D-6. Use of the same equipment was recommended for both sunflower seed and peanut processing by Anderson International, which provided the equipment costs except for bulk storage of seeds, hulls, meal, and oil and the boiler and its accessories. Note that the hulls will be separated from the peanuts but not from the sunflower seeds. If the gross heating value of the hulls were about 7,500 Btu/pound, then these could be used to generate 13,300 pounds per hour of steam (at 75 percent boiler efficiency) compared to the plant requirement of about 3,200 pounds per hour. Although the plant was actually costed on the basis of an oil or gas-fired boiler, it is believed that the incremental cost of a hull-fired boiler-incinerator plus a small 6-hour hull holding bin would nearly be covered by the $63,000 cost estimate for the large 1-day hull storage bin now included in the cost estimate.

Costs for land and site improvements such as fences, roads, truck dock, and railroad siding have been excluded from this estimate. It has been assumed that the plant would only be installed at an existing elevator because of the infrastructure thus gained.

Annual operating costs are presented in Table D-7. In general, the operating costs for both peanut and sunflower oil recovery are the same except that has been assumed that waste hulls will be used to fire the peanut oil plant.

Two types of economic analyses have been performed for the commercial plant. The "irregular" economic analysis has been performed, using the same

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TABLE D-6. CAPITAL INVESTMENT FOR COMMERCIAL UNIT

Basis[a]

Hourly feed rate:	16,667 pounds/hour seeds
Operation :	7,920 hours per year (330 days per year, 24 hours per day)
Efficiency of Operations :	95 percent
Sunflower seeds required:	62,701 tons/year
Filtered and winterized oil produced :	5,890,540 gallons/year
Meal cake produced (6 percent oil) :	40,020 ton/year
Peanut seeds required :	62,701 tons/year
Filtered and winterized oil produced :	7,533,780 gallons/year
Waste hulls :	10,659 tons/years
Meal cake produced (4 percent oil) :	23,186 tons/year

Equipment Items	Cost, Dollar Peanuts or Sunflower Seeds
Main seed storage bin - 5-day inventory, 83,333 bushel at $4/bushel	$333,330
Seed and by-product handling equipment (see below)	-
Bulk weigh scales	12,050
Seed preparation equipment: stoner, cracker, rolls and screens, and dehuller	55,000
Surge bin	18,000
Stacked cooker-dryer	179,750
Mega 460 expeller presses (2 each)	510,000
Overflow bin	9,040
Screening tank	21,080
Unfiltered oil tank	2,170
Portable agitator	1,960
Circulating oil pump	7,500
Six heat exchangers	15,570
Filter press	15,570
Hopper and filter press platform	14,900

(a) The capacity of this plant is abo-t 22 percent less than the plant discussed in Table D-1.

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TABLE D-6. (Continued)

Equipment Items	Cost, dollars Peanuts or Sunflower Seeds
Filtered oil tank	$ 2,100
Rotary oil transfer pump	1,195
Oil winterization unit	50,000
Meal cake grinder with magnet	17,175
Air compressor	3,500
Boiler, oil-or gas-fired, 187.5 hp	45,400
Boiler accessories: water softener, blowdown tank, boiler feed system	11,500
Oil storage tank: About 2 months' inventory, 1.25 million gallons	260,000
Miscellaneous materials handling equipment	40,000
Spare parts for one year of operation	106,750
Start-up training	14,950
Building: 40 feet by 100 feet at $40/square foot	160,000
Construction costs:	
Of seed and other storage bins - included above	-
Of equipment supplied by Anderson International 45 percent of 1,013,490	456,070
Of boiler and boiler accessories - 100 percent of $56,900	56,900
Of oil storage tank - 100 percent of $260,000	260,000
Of building - included above	-
SUBTOTAL	$2,718,390

	Cost, Dollars Sunflower	Peanut
Meal storage bin		
Sunflower - 3 days' inventory, 22,000 bushel at $4.25/bushel	$93,500	
Peanut - 3 days' inventory 6,000 bushel at $4.50/bushel		$27,000
Hull storage bin - 1 day inventory 14,000 bushel at $4.50/bushel		63,000
SUBTOTAL	$ 93,000	$ 90,000
GRAND TOTAL	2,811,890	2,808,390
ASSUME	2,810,000	2,810,000

(a)The capacity of this plant is about 22 percent less than the plant discussed in Table D-1.

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TABLE D-7. ANNUAL OPERATING COSTS FOR COMMERCIAL UNIT

Basis: See Table D-6.

Cost Item	Annual Costs, Dollars Sunflower	Peanut
Utilities		
Power 6,336,000 kw-hr at $0.05/kw-hr	$ 316,800	$ 316,800
Fuel		
Sunflower - 272,000 gallons at $1.20/gal	326,400	-
Peanut - Use hulls	-	0
Water: 105,000,000 gallons/year at $0.25 per 1,000 gallons	26,140	26,140
Direct Labor		
3 men per shift at $14.30 per hour including fringes	376,100	376,100
Supervision at 15 percent of direct labor	56,410	56,410
Maintenance - 4 percent of capital investment	112,400	112,400
Factory supplies - 0.5 percent of capital investment	14,050	14,050
Spare parts used during year	106,750	106,750
Factory overhead - 50 percent of direct labor maintenance and supervision	272,460	272,460
Insurance and property tax - 3 percent of capital investment	84,300	84,300
(TOTAL, excluding capital charge and tax considerations)	$1,691,810	$1,365,410
Zero Profit Emergency Economics Analysis		
Plus Capital Charge(a)		
Payment of both principal and interest at 15 percent interest over 10 years	559,900	559,900
Less income tax credits and deductions:		
Investment tax credit: levelized over 10 years on equipment at 15 precent discount rate $505,660 in first year	(87,610)	(87,610)
Depreciation: 5 year straight line on equipment and 15 years straight line on buildings levelized over 10 years at 15 percent discount rate, times effective tax rate of 50 percent		
$505,660 first 5 years for equipment	(168,860)	(168,860)
$ 10,670 first 15 years for building(b)	(10,670)	(10,670)

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TABLE D-7. (Continued)

Cost Item	Annual Costs, Dollars Sunflower	Peanut
Interest: Declining interest payments over 10 year levelized over 10 years at 15 percent discount rate, times the effective tax rate of 50 percent. $421,500 first year and $73,030 in 10th year.	(160,060)	(160,060)
TOTAL, including tax considerations	$1,824,510	$1,498,110
Normal Economic Analysis		
Total, excluding capital recovery factors	1,691,810	1,365,410
Capital recovery factors: Depreciation, profit, interest, and income taxes - 30 percent of capital investment	843,000	843,000
TOTAL Cost of Conversion	$2,534,810	$2,208,410

(a) This method of calculating capital charge and income tax credits and deductions is unrealistic for this plant. It is done for comparison only. (See text.)

(b) Final 5 years of depreciation on building is not included.

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type of calculations employed for the on-farm and cooperative-sized plants. This analysis determines the costs of operation at break-even assuming a no-profit situation. Therefore, the irregular analysis is probably unrealistic unless a large cooperative venture were formed based entirely on borrowed capital. The normal economic analysis would be similar to that performed for an on-going commercial enterprise which would be based on significant equity capital, combined with debentures and would seek profits, and pay taxes. In addition, a longer plant life (about 20 years or more) would be anticipated.

The peanut meal cake produced in the commercial facility after dehulling would have a much higher protein content than the meal cake produced without dehulling the peanuts, about 45 versus 32.5 percent, respectively. It has been assumed that the value of such meal cake is $195 per ton to prepare the economic summary presented in the next section.

Summary of Economic Analysis

A summary of the economic analysis of the on-farm, cooperative and commercial units is presented in Table D-8. The economies of scale related to the commercially sized operation are clearly evident, regardless of whether zero profit emergency economics analysis or normal economics analysis is performed. The low cost of on-farm operation compared to the cooperative unit can be attributed to use of some existing or used equipment, low cost of labor for operation and plant construction, and low overheads.

Pollution From Oilseed Expelling

Based on the designs assumed for the on-farm, cooperative, and commercial oilseed expelling facilities, the processes appear to be minor sources of pollution. Operation of the on-farm unit would result in about 90 filter cartridges (similar to automobile oil filters) per year partially filled with oil plus about 3-55 gallon drums per year filled with seed solids settled from unfiltered oil while producing 6,670 gallons of vegetable oil. The meal cake should find markets as animal feed. Operation of the cooperative scale facility would result in only oil-soaked sludge with filter cloths which should

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TABLE D-8. SUMMARY OF ECONOMIC ANALYSIS

Basis: See prior text and tables.

Zero Profit Emergency Economics Analysis

Sunflower	On-Farm	Cooperative	Commercial
Seeds processed, tons/year	86.7	1,632	62,700
Gallons oil produced per year	6,670	147,400	5,890,500
Gallons diesel fuel equivalent	6,350	140,400	5,610,000
Meal produced, tons/year	60.5	1,053	40,020
Conversion cost, dollars/year	8,321	200,700	1,825,000
Raw material cost, dollars/year	11,271[a]	244,800[b]	12,540,000[c]
Less by product meal credit[d]	7,865	136,900	5,203,000
Total cost, dollars/year	11,727	308,600	9,162,000
Cost per gallon diesel oil equivalent, dollars/gallon	1.85	2.20	1.63
Peanuts			
Seeds processed, tons/year	86.7	1,632	62,700
Gallons oil produced per year	8,510	179,600	7,533,800
Gallons diesel fuel equivalent	8,110	171,100	7,175,000
Meal produced, tons/year	53.4	930	23,190
Conversion cost, dollars/year	9,203	201,200	1,498,100
Raw material cost, dollars/year(e)	13,525	293,760	15,048,000
Less by product meal credit	8,010	139,600	4,521,300
Total cost, dollars/year	14,718	355,360	12,024,800
Cost per gallon diesel oil equivalent, dollars/gallon	1.81	2.08	1.68

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TABLE D-8. (Continued)

Normal Economic Analysis			
Sunflower	On-Farm	Cooperative	Commercial
Conversion cost, dollars/year			2,534,800
Raw material cost, dollars/year			12,540,000
Less by-product meal credit			5,202,900
Total cost, dollars/year			9,871,900
Cost per gallon diesel fuel equivalent dollars/gallon			1.76
Peanuts			
Conversion cost, dollars/year			2,208,400
Raw material cost, dollars/year			15,048,000
Less by-product meal credit			4,521,300
Total cost, dollars/year			12,735,100
Cost per gallon diesel fuel equivalent, dollars/gallon			1.77

(a) Assumes on-farm value of $130 per ton.

(b) Asumes local value of $150 per ton.

(c) Assumes commercial market value of $200 per ton.

(d) Assumes by-product credit of $130 per ton for sunflower meal, $150 per ton for peanut meal from the on-farm and cooperative units, and $195 per ton for peanut meal from the commercial unit.

(e) Peanut acreage allotments distort costs. Incremental production of less than food-grade peanuts assumed at 20 percent more than sunflowers.

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probably be disposed of by incineration at a nearby municipality. The design assumes that oil tank settlings can be recycled to the oil expeller similar to commercial practice. The settling of solids in tanks is not practiced in the commercial unit, but rather, all solids in the oil are recycled back through the expeller and are eventually extruded with the meal. Some minor quantities of a waxy sludge will result from the winterization process. This sludge could also be disposed of at a municipally operated incinerator. However, if more of the peanut hulls generated in the operation of the commercial unit were not used as boiler fuel (or incinerated at the plant), then major transportation and handling problems would occur in their proper disposal to the land as a soil conditioner. Proper design must be performed of the hull-fired boiler or incincerator to avoid high levels of particulate in the flue gas.

Energy Requirements for Oil Expelling

Energy requirements for conversion of the oilseeds to vegetable oils and meal in various scales of operation are presented in Table D-9. The values presented are developed from the tables reporting capital and operating costs in a separate section of the report. The gross energy basis calculation presented is based on a practical value of the energy required to produce electricity in a typical utility plant operating at 33 percent efficiency (10,342 Btu/kw-hr). A net energy basis calculation based on 3412.76 Btu/kw-hr would be theoretical and is not shown.

Gross energy requirements to produce a gallon of vegetable oil range from about 15,000 to 20,000 Btu except for the processing of peanuts in the commercial unit in which by-product hulls were used as fuel. If fuel oil were used, the energy requirement in this case would have been 13,750 Btu's per gallon.

Comparison of the on-farm unit with the other units clearly shows that energy conservation that would result from not heat treating seeds prior to expelling, while comparison of the commercial unit with the cooperative unit shows a reduced energy consumption in the larger plant. Because of the higher oil content in peanuts than sunflower seeds, more energy is required for sunflower oil expelling than for peanut oil expelling on a per gallon basis.

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TABLE D-9. ENERGY REQUIREMENTS FOR VEGETABLE OIL EXPELLING

	On-Farm[a]	Cooperative	Commercial[b]
Sunflower Processing			
Gallons oil produced per year	6,670	147,400	5,891,000
Power requirement, kw-hr/year	10,050	207,500	6,336,000
Fuel requirement, gallons fuel oil/year	0	5,620	272,000
Gross Energy Basis, Millions of Btu's/year[c]			
Power	103.9	2,146	65,520
Fuel	0	787	38,080
TOTAL	103.9	2,933	103,600
Btu's per gallon of oil	15,580	19,900	17,590
Peanut Processing			
Gallons oil produced per year	8,510	179,600	7,534,000
Power requirement, kw-hr/year	12,220	209,700	6,336,000
Fuel requirement, gallons fuel oil/year	0	5,620	0[d]
Gross Energy Basis, Millions of Btu's/year			
Power	126.4	2,169	65,520
Fuel	0	787	0
TOTAL	126.4	2,956	65,520[e]
Btu's per gallon of oil	14,850	16,460	8,697

(a) The on-farm unit does not heat-treat the seed.

(b) The values in the table for peanut processing assume that the hulls will be used as boiler fuel in lieu of fuel oil.

(c) The gross energy calculation assumes a boiler efficiency of 33 percent where the power is produced or 10,341.7 Btu/kw-hr and 140,000 Btu/gallon for fuel oil.

(d) If fuel oil were used instead of hulls, then the energy used in the form of fuel would have been 38,080 million Btu's/year.

(e) If fuel oil were used instead of hulls, then the gross energy used per gallon would have been 13,750 Btu/gallon.

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APPENDIX E

DIESEL FUEL SPECIFICATIONS AND VEGETABLE OIL PROPERTIES

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APPENDIX E

DIESEL FUEL SPECIFICATIONS AND VEGETABLE OIL PROPERTIES

The American Society for Testing Materials (ASTM) methods for measuring key diesel fuel properties were developed for petroleum products. Table E-1 summarizes the methods and presents recommended limiting values for several No. 2 diesel fuel properties. This information is provided in ASTM D975 Standard Specification for Diesel Fuel Oils.

Diesel engines will operate on fuels whose properties are outside of these specifications, and not all fuels sold commercially will meet the specifications. However, for best overall performance in the widest range of engine types, ambient conditions, and service applications, the fuel specifications should be close to or within these values or ranges.

Significance of Fuel Specifications

Several of the fuel properties listed in the table are known to have important effects on engine performance and operation. These are described below:

Viscosity. Fuel viscosity may affect the performance of the fuel injection system and the fuel spray characteristics. Low viscosity can result in excessive wear in some injection pumps and engine power loss due to pump and injector leakage. High viscosity might result in filter damage and pump damage due to high flow resistance. High viscosity might also degrade the spray pattern so that fuel ignition and combustion characteristics are deteriorated.

Cetane Number. Engine performance factors which may be influenced by cetane number are: cold starting, warmup, engine roughness, acceleration, combustion chamber deposits, and smoke density. A cetane number lower than that required of a specific engine may lead to deterioration in one or more of the above factors.

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TABLE E-1. SUMMARY OF ASTM MEASUREMENT METHODS AND SPECIFICATIONS FOR KEY DIESEL FUEL PROPERTIES[a]

Ignition quality (Cetane No.)	ASTM D613 - standard engine operated under prescribed conditions and is based on measurement of rate of pressure rise. Should be at least 40.
Heating value	ASTM D240 - measures heat of combustion by bomb calorimeter. Usually in 140,000 Btu/gallon.
Viscosity	ASTM D445 - measures resistance of the oil to flow. 1.9 cs (min) to 4.1 cs (max).
Pour point	ASTM D95 - measures the lowest temperature at which the oil will flow under prescribed conditions.
Cloud point	ASTM D2500 - measures the temperature at which a precipitate begins to form under prescribed conditions. 6 C is maximum temperature.
Flash point	ASTM D93 - measures lowest temperature at which a test flame will cause ignition of vapors under prescribed conditions. 52 C minimum.
Ash	ASTM D482 - measures ash residue after complete combustion of oil under prescribed conditions. 0.01 percent is typical.
Volatility	ASTM D86 - measures fraction of oil "boiled" off at specific temperatures under prescribed conditions. The 90 percent point is reached between 282 and 338 C.

(a) Commercial No. 2-D diesel fuel need not meet all of these specifications.

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Heating Value. The heating value directly affects the power produced by a given quantity of fuel (assuming combustion efficiency is constant). Thus, a fuel with lower heating value will produce less power for the same weight or volume of fuel consumed. Diesel engine fuel systems are usually calibrated on a volume basis, hence, the potential power loss due to use of an alternative fuel can be computed using the ratio of the volume-based heating values of the alternative fuel and standard diesel fuel. Fuel systems can sometimes be recalibrated for a lower-heating-value fuel to permit the engine to produce the same power as with standard fuel.

Flash Point. Flash point relates primarily to safety precautions required for storage and handling of the fuel. A lower flash point would require greater precautions.

Volatility. This is usually measured or based on distillation tests. However, vegetable oils have a tendency to decompose or crack upon heating. As such, this test would provide a poor correlation with engine performance.

Cetane Measurement Problem

The standard cetane test, ASTM D613, has been reported to be not applicable to vegetable oil fuels.* Tests on several different vegetable oils were performed at Waukesha Engine Company using the standard test procedure. Six of the 11 oils tested produced pressure rise rates that were not rapid enough to trigger the "ignition delay" meter, so no cetain number could be obtained. Cetane numbers that were obtained ranged between 20.5 and 32.5 Southwest Research Institute, using visual observation of the pressure rise rates, estimated the cetane numbers of the same

*Private communication from Professor Carroll E. Goering, University of Illinois, at Urbana, Illinois.

vegetable oils to be 8 to 10 points higher. Actual experience with these vegetable oils in diesel engines would indicate that cetane numbers on the order of 30 to 40 are more believeable, thus, a modification to the cetane measurement procedure appears to be called for. The ASTM Committee responsible for this procedure has indicated that a review of the test procedure will be started soon.

Fuel-Related Properties for Fats and Oils

A tabulation of fuel-related properties for several vegetable oils and animal fats is presented in Table E-2. The data have been obtained from several sources. However, only in the last few years has research been directed towards vegetable oils as fuels. Agreement between sources is seen with a few discrepancies. Data variances can be the result of differing measurement techniques in addition to normal experimental error.

The fuel properties listed are thought to be a good initial basis of comparison for diesel fuel substitutes. These are discussed below:

Viscosity. Vegetable oils and fats typically have viscosities one or two orders of magnitude greater than diesel fuels. This high viscosity can be detrimental to engine performance. Also, very little data are available on low temperature (-20 to 0 C) viscosity, which is related to cold-start problems. Several researchers have found it impossible to start an engine on pure vegetable oil without a preheat. This problem is lessened when the vegetable oil is diluted with diesel fuel.

A possible solution to the high viscosities of vegetable oils is to convert them to an ethyl or a methyl ester mixture. The mixture would contain the ester, some of the original vegetable oil, and some alcohol. The ester has a distillation curve much closer to that of diesel oil, but most significant is the lower viscosity of the ester, about 10cs at 40 C for sunflower oil ester, which compares favorably with that of diesel oil.

Cetane Number. Although a minimum cetane number for diesel fuel is 40, a cetane number of 48-54 is typical. Most vegetable oils have been

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TABLE E-2. PROPERTIES OF SELECTED FATS AND OIL COMPARED WITH NO. 2 DIESEL FUEL

Oils	Viscosity, cs @100f	Cetane, number	Heating Value, MJ/Kg	Flash Point, C	Titer Point, C	Specific Gravity, @15.5 C
Diesel fuel, No.2	2.0-3.6	48-54	42.7-45.8	39-52	--	0.82-0.84
Soybean	28-37[a,b,c,n]	21.7[i], 36[n]	37-39.3[a,f]	282-329[a,b,c,o]	21-27[b,c]	0.924-0.928[c,d]
Cottonseed	35.9-38.9[c,n]	40[e]	39.1[f,l]	252-323[c,o]	30-37[c,d,m]	0.921-0.925[c,d]
Sunflower	30.6-36[c,g,h,i,j]	33.4-47[e,g,h]	39.2-39.7[e,g,h,i,j]	274-330[e,i]	16-20[c,d,m]	0.922-0.926[c,d,g]
Safflower	32.7[j]	N/A	39.5[j]	317[c]	15-18[c,d]	0.925-0.928[c,d]
Peanut	36.5-41.2[a,g]	36.6-41[e,g]	37-40.1[a,k,g,l]	282-319[a,o]	26-32[c,m]	0.917-0.921[c,g]
Crambe	N/A	N/A	39.8*	N/A	N/A	N/A
Castor bean	285-297[a,c,i]	N/A	39.3*	229-295[a,o]	N/A	0.958-0.969[c,d]
Chinese tallow (Stillingia oil)	N/A	N/A	N/A	256[o]	39-42	0.940-0.946[d]
Rapeseed	50.6-51.3[c,j,n]	32.5[i]	39.9*	163-288[d,m,o]	11-15[c,m]	0.913-0.916[d]
Canola	35.6[k]	33.5[q]	39.5[k]	190-300[q]	N/A	0.920[k]
Corn	30-36*	N/A	39.8[l]	254-326[c,o]	14-20[c,d,m]	0.922-0.926[c,d]
Linseed	27.2-29.6[c,i]	29.6[i]	38.7-39.0*[f]	222[o]	19-21[c,d,m]	0.931-0.938[c,d,m]
Lard	44.4[c,n]	N/A	39.3*	260[o]	32-43[c,m]	0.934-0.938[c]
Inedible tallow		N/A	39.3*		40-46[m,o]	
Grease		N/A	39.3*		36-38[m,o]	

* Battelle estimate.
N/A = Not available.

Footnotes: See following pages

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Footnotes to Table E-2

(a) Everett H. Pryde, Ed., Fatty Acids, The American Oil Chemists Society, Champaign, Illinois, 1979.

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(c) V.C. Mehlenbacher, The Analysis of Fats and Oils, The Garrard Press, Champaign, Illinois, 1960.

(d) K.A. Williams, Oils, Fats and Fatty Foods, 3rd Ed., The Blakiston Co., Philadelphia, 1950.

(e) D.M. Bacon, et al., "The Effects of Biomass Fuels on Diesel Engine Combustion Performance" Proceedings of the IV International Symposium on Alcohol Fuels Technology, P 431-439, October 1980 (Brazil)

(f) J. Baldwin, B. Cochran, and L. Daniel Jr., "Vegetable Oils for Diesel Engines", 1981 Beltwide Cotton Production-Mefhanization Conference, January 7, 1981 New Orleans.

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(h) J.J. Bruwer, Dr. B. Boshoff, F. Hugo, J. Fuls, C. Hawkins, A. Van der Walt, A. Engelbrecht, "The Use of Sunflower Seed Oil in Diesel Engineed Factors", Department of Agriculture and Fisheries, Republic of South Africa.

(i) C.E. Goering and D.R. Hunt, "Vegetable Oil-Solvent Blends as Diesel Fuel", from 1980 Alcohol and Vegetable Oil Seminar.

(j) C.L. Peterson, et al., "Vegetable Oil as an Agricultural Fuels for the Pacific Northwest", Agricultural Experiment Station, University of Idaho, Bulletin No. 598, February, 1981.

(k) R.C. Strayer, "Canola Oil as a Fuel for Diesel Engines", CSAE Paper No. 80-302, August 3-7, 1980 (Annual AIC Conference).

(l) "Sunflowers, Are They a Practical Alternative to Diesel Fuel", Ag. Energy, Vol. 1 (No. 1), pp 2-3, April 24, 1980.

(m) Daniel Swern, Ed., Bailey's Industrial Oil and Fat Products, Chapter 6 Interscience Publishers, New York, 1964.

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(n) Silvio de Oliveira, Jr., Otavio de Mattos Silvared and Hernani Brinati, "The Use of Vegetable Oils in Internal Combustion Engines", proceedings of the IV International Symposium on Alcohol Fuels Technology, pp 1067-1073, Brazil, October, 1980.

(o) Fire Protection Guide on Hazardous Materials, 7th Ed., National Fire Protection Association, Boston, 1978.

(p) E.F. Obert, Internal Combustion Engines and Air Pollution, 3rd Ed., Harper and Row, New York, 1973.

(q) Private communication from Professor R. C. Strayer, University of Saskatchewan, At Saskatoon, Saskatchewan.

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reported to have a cetane number in the 30 to 40 range with some reported as low as 20.5. However, there is a question as to the applicability of the present cetane measurement techniques to vegetable oils.

Heating Value. The vegetable oils consistently appeared to have a heating value 85 to 90 percent that of diesel fuel on a weight basis. However, vegetable oil would be only slightly less or equal to diesel fuel heating value on a volume basis. Most of the Battelle estimates were based on the oils composition, with inedible tallow and grease assumed to be similar to lard.

Flash Point. Vegetable oils have significantly higher flash points than diesel fuel. However, ignition of the pure material would be difficult (cold-start problems), but the presence of diesel fuel in a blend could alleviate this (at times kerosene is added to diesel fuel to improve cold starting).

Titer Point. Titer point is an indication of the solidification temperature of the fats.

Specific Gravity. Generally, vegetable oils have densitities 10 to 17 percent greater than that of diesel fuel. This can be a technical advantage in offsetting the vegetable oils' lower heating value per unit weight; however, it adds to the cost per unit of volume.

Blends

Two types of blends can be employed to overcome the problems of using fats and oils in diesel engines. Vegetable oils have many of the characteristics of promising diesel fuel substitutes. The major problem areas are sketched in Figure E-1. In addition to high viscosity, problems will be encountered with ignition temperature, vapor pressure, and

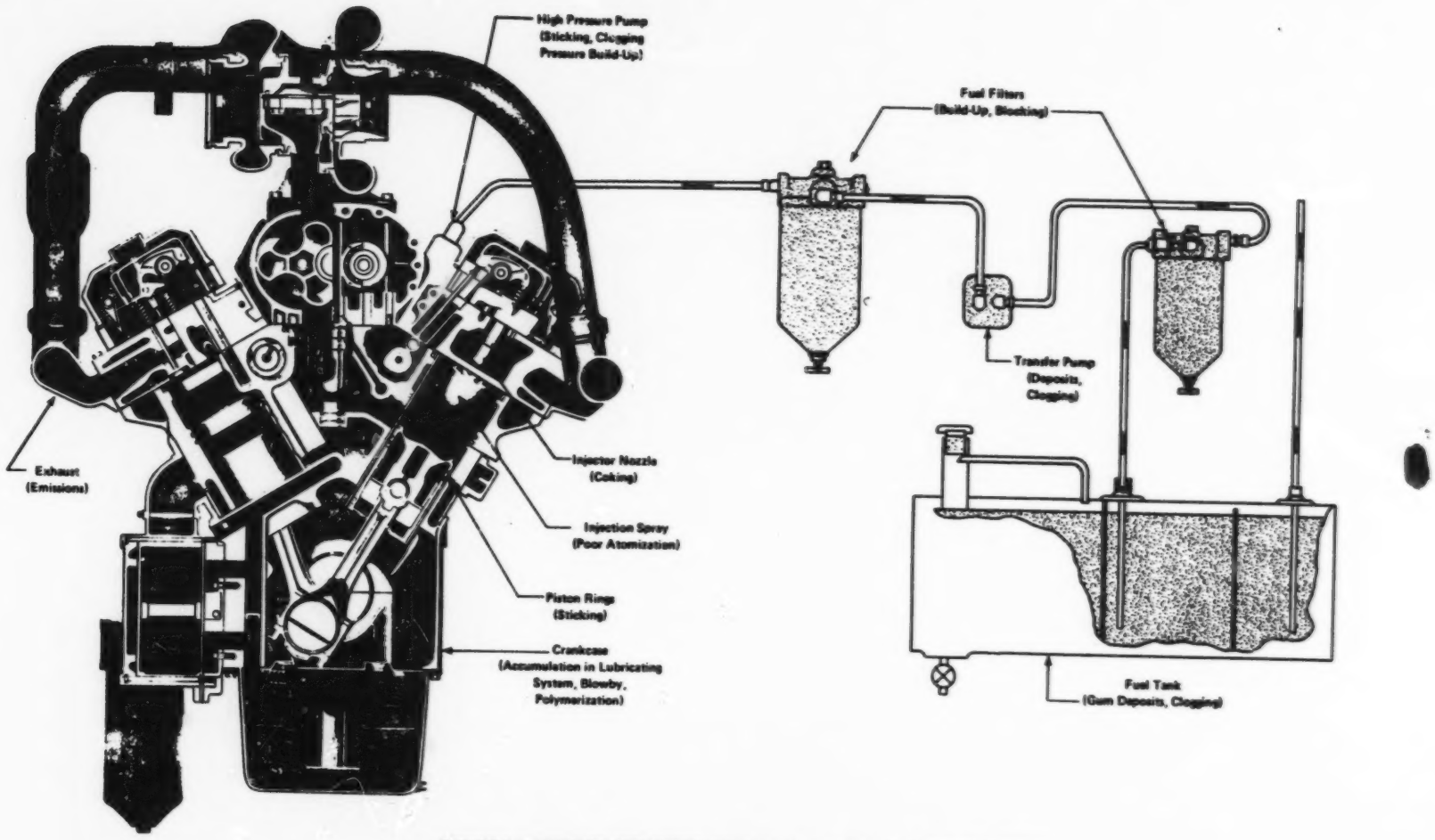

FIGURE E-1. PROBLEM AREAS WITH VEGETABLE OILS IN DIESEL ENGINE SYSTEMS

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volatility. Clogging of the fuel system and coking of the injectors can be greatly reduced by blending with diesel fuel. Blending might also help reduce fouling, or polymerization, of the lube oils. These fuel substitutes can also be employed in boilers, which have a greater tolerance of fuel type.

Microemulsion diesel fuels have been made on an experimental basis and evaluated by Fuel Systems, Incorporated (FSI)/Battelle-Columbus, Allis Chalmers/U.S. Department of Agriculture, Southwest Research Institute, John Deere, and North Dakota State University. The Fuel Systems, Incorporated microemulsion fuel blend is covered by, and described more fully in, U.S. Patent No. 4,083,698. This fuel is a modified vegetable oil which, when in mixture with alcohol and water, can be blended in all proportions with No. 2 diesel fuel. The blend forms a solution which appears clear and remains stable for a minimum of several months. The FSI/diesel fuel blend is a true water-in-oil microemulsion with a high water tolerance. The fuel was able to absorb water to more than half the volume of modified vegetable oil with no signs of instability.

Evaluation of Exhaust Emissions Characteristics of Vegetable Oil Fuels

If vegetable oils are to be used in diesel trucks or passenger cars, it must be shown that their use either as a diesel fuel extender or as a complete substitute does not result in an unacceptable increase in the regulated exhaust emissions and does not produce non-regulated emissions that could be shown to be hazardous to human health. At present there are no emissions regulations for diesels used in farm machinery and off-road construction equipment, however, the concern for health hazards must still be considered an important factor.

The regulated emissions (for road vehicles) are unburned hydrocarbons, oxides of nitrogen, carbon monoxide, and smoke. In the 1983 model year passenger-car and light truck diesels will be required to meet a particulate standard, and in 1984 heavy-duty trucks will have a particulate standard.

Non-regulated emissions that have been identified as of some potential concern include: sulfates, nitrosomines, aldehydes, reactive organics, oxygenates, and polynuclear aromatic hydrocarbons. The latter are usually associated with the particulates in the exhaust.

A third concern with respect to the exhaust emissions characteristics of vegetable oil fuels is the biological activity of the organic compounds associated with the particulates.

Table E-3 summarizes the engine emissions and emissions characteristics that should be considered in evaluating vegetable oils as substitute fuels for diesel engines.

TABLE E-3. EVALUATION OF EMISSION CHARACTERISTICS OF VEGETABLE OIL FUELS

Regulated emissions:	Unburned hydrocarbons (HC) Oxides of nitrogen (NO_x) Carbon monoxide (CO) Smoke Particulates
Non-regulated emissions:	Nitrosamines Aldehydes Sulfates Polynuclear aromatic hydrocarbons (PAH) Reactive organics Oxygenates
Biological Activity:	Ames Bioassay Test on Organic Compounds Associated with Particulates

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